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METHOD OF TESTING CHRONOMETERS AT THE U. S. NAVAL OBSERVATORY.

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In the appropriation for the fiscal year ending June 30, 1883, provision was made for the construction of a house in which to test chronometers at different temperatures. Under that provision the present temperature room was built.

It is situated on the north side of the Observatory, in an angle of the east wing, directly in front of and connecting with the chronometer room proper. This is a cool and comparatively well-shaded place. The foundation is of brick, and starts from solid earth three feet below the surface, and reaches two feet six inches above it. From just below the surface it is made double, with an air space of the width of one brick between the walls. On top of the foundation, and made tight with cement, is placed a plate of slate; on this plate, and cemented to it, is the sill of the house.

The exterior dimensions are eleven feet eight inches square by ten feet high from the foundation to the eaves, and twelve feet to the ridge. The walls and ceilings are double, made of well-seasoned

lumber, the plank being inch-thick pine, tongued and grooved, placed horizontally, leaving a clear space of eight inches between. This space is filled with dry and well-seasoned sawdust, making the sides and ceiling ten inches thick, of wood.

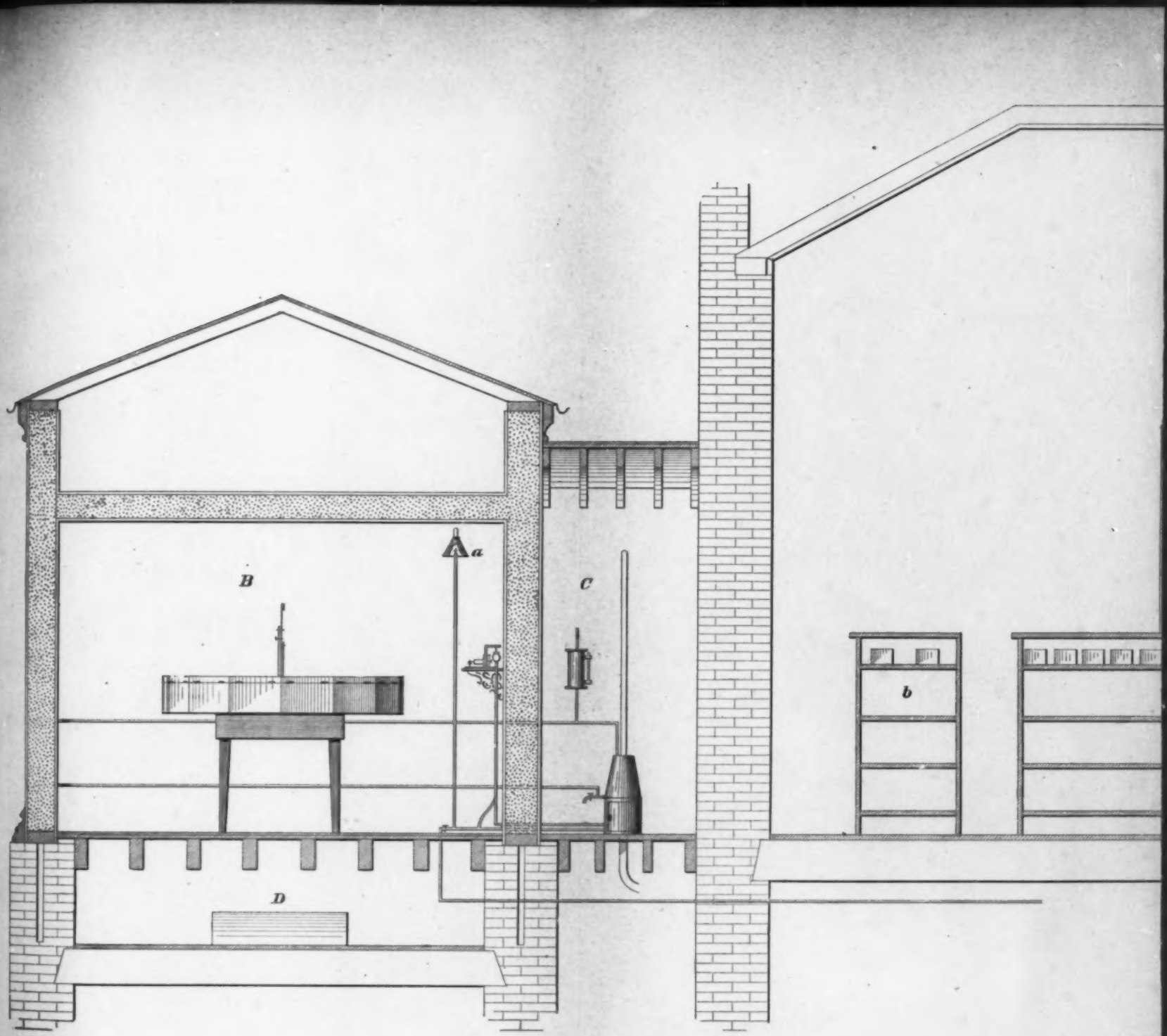
It is covered with a tin roof, leaving an air space of from two to four feet between the upper ceiling and the roof.

There are two floors, the lower of which is on a level with the surface of the earth, and is made of ordinary pine flooring, built in, and made tight with the foundation. The upper one is at the top of the foundation, and is made of strips two inches wide by one inch thick, laid so as to leave an inch space between them, the whole covered with sheet zinc, turned up two inches at the sides, and tacked to the inner wall with thick felt between the zinc and the wall. This makes the room tight from the space between the floors, which is the ice receptacle or refrigerator, in which the air is at or near saturation when ice is used. The refrigerator is eight feet square by two feet six inches high, and is capable of holding two thousand pounds of ice. A few hundred, however, is all that will be usually required, and for this there are two troughs, one on either side of the centre, six feet long by two feet wide, and eight inches deep, lined with zinc, and fitted with drain pipes leading to the outside of the building. These troughs will hold three or four hundred pounds each. To get into the refrigerator, there are double doors through the foundation, one at the outer, and the other at the inner surface of the wall, each fitted tight with a lining of felt, leaving a space between the doors of the thickness of the foundation.

The temperature room is ten feet square by seven feet high, and is also fitted with double doors, the outer one of which connects directly with the main clock and chronometer room. Both doors are made tight with linings of felt, and the inner one has a large plate of French glass in its upper half, through which the face of the mean time standard clock can be plainly seen when the outer door is open. With this clock all chronometers are compared daily.

Between the doors, and made tight with them, is a passage-way, four feet long, four feet wide and seven feet high, made in the same manner as the house, with double walls and ceiling. It is large enough for two persons to stand between the doors and close one before opening the other, thus excluding a rush of outside air of a different temperature.

For lighting the room there is one window on the north side,


a
B
C
b
D

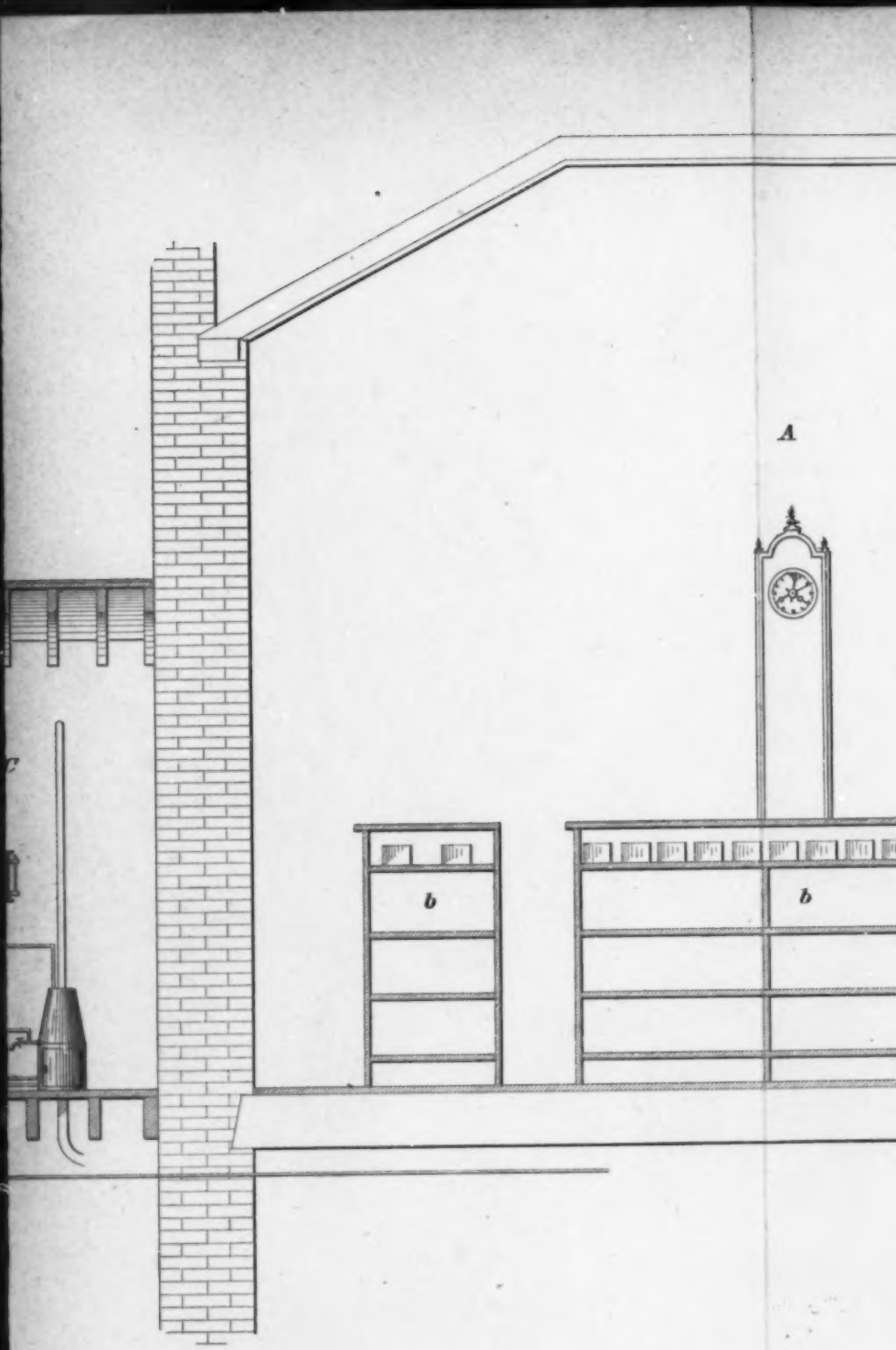
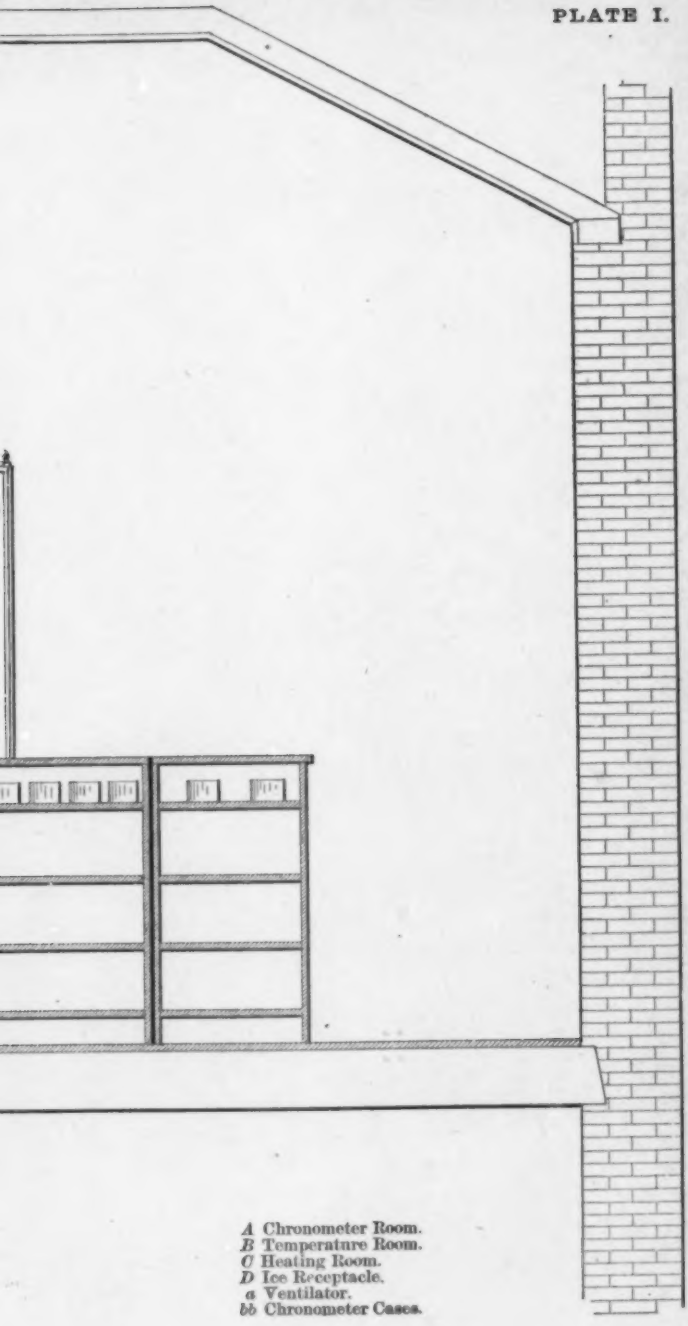
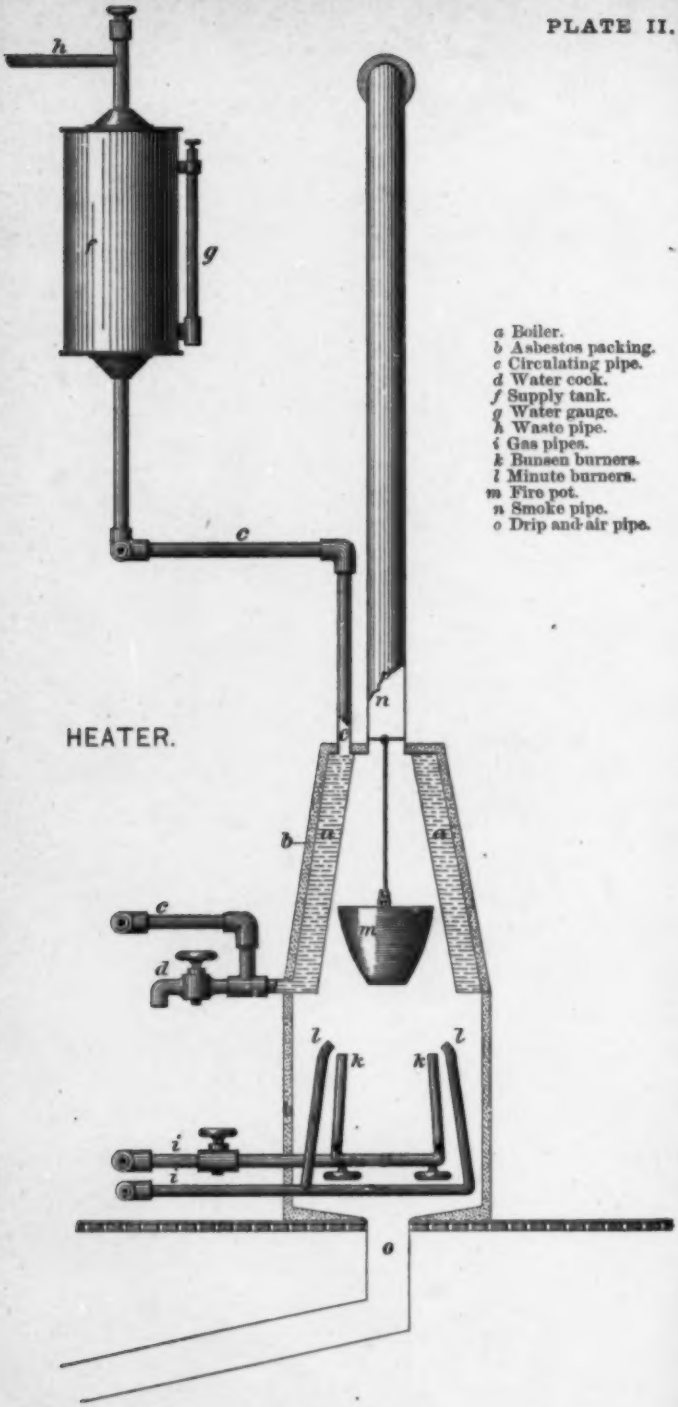

A
b
b

PLATE I.



A Chronometer Room.
B Temperature Room.
C Heating Room.
D Ice Receptacle.
a Ventilator.
bb Chronometer Cases.

PLATE II.



a Boiler.
b Asbestos packing.
c Circulating pipe.
d Water cock.
f Supply tank.
g Water gauge.
h Waste pipe.
i Gas pipes.
k Bunsen burners.
l Minute burners.
m Fire pot.
n Smoke pipe.
o Drip and air pipe.

opposite the door, having a double sash. The outer one is three feet high by two feet wide, and the inner one three feet high by two and a half wide; the casing is beveled so as to admit light to all parts of the room. Both sashes are screwed in with felt between the casing and the sashes, leaving an air space of six inches between the glasses.

The room is heated by circulation of hot water (the fuel being gas controlled by electricity), and is cooled by ice in the refrigerator when a temperature is required below that of the outside atmosphere.

In a small room, two and a half feet by three and a half, and six feet high, built between the temperature and main chronometer rooms, and connecting by door with the small passage-way, is a small copper boiler, made in the shape of the frustum of a cone. The boiler and heating space underneath are covered with a casing of copper, leaving a space of half an inch between the boiler and casing, which is filled with asbestos packing.

From the top of the boiler leads the circulating pipe (of iron and an inch in diameter), which goes through the wall, where it is surrounded by asbestos packing, into the temperature room, thence twice around the room, back through the wall and into the boiler at its lowest point, making a fall of eighteen inches in circulating. A water-cock is placed on the return pipe near the boiler for drawing off the water when not in use.

Above the boiler and connecting with the circulating pipe is a supply tank of galvanized iron, holding about one gallon of water. This is fitted with an opening at the top for filling, a glass water-gauge at the side, and a waste-pipe leading from the top out through the side of the building. This latter is a safety as well as an overflow pipe, for should the control cease to act and too much heat be generated, the steam would escape through this pipe and relieve the pressure in the circulating coil.

A gas pipe leads from the main pipe of the Observatory through the foundation up into the temperature room, with its main cock just above the floor. Thence the pipe is led up the wall about four feet, over a little shelf; thence down to the floor, through the wall into the heating room, and under the boiler where the two Bunsen burners are attached. In the horizontal part of this pipe, over the small shelf, is a spring valve acting perpendicularly, the spring keeping the valve open. The stem of the valve projects above the box, and is worked automatically by a lever attached to the armature of an electro-magnet.

A small gas pipe leads from the main pipe, before it reaches the automatic valve, to the top of the room, with its burner under a funnel-shaped ventilator, for increasing the draught and regulating the hygrometric state of the room.

Another small gas pipe leads from the same point through the wall into the heating room and under the boiler, where two minute burners are attached, the flames from which are directed, one over each Bunsen burner. These are always kept burning when the room is in use.

A two-inch pipe leads through the floor and foundation to the outside for supplying cold air as required. This, with the ventilator, is regulated by hand.

Suspended over the Bunsen burners in the hollow space of the boiler is a fire-pot to deflect the flames against the sides, and from the top of this space a small copper pipe leads up to the ceiling and out through the wall, for the escape of the products of combustion. Directly under the burners, leading through the floor and out through the foundation, is a two-inch lead pipe to carry off condensed vapor and to supply oxygen to the burners. A small, tight-fitting door opens into the combustion chamber.

The supply of gas is controlled by electricity through a mercurial thermostat, the stem of which is made and graduated like an ordinary thermometer, but which is open at the top.

The bulb is made of a thin glass tube coiled into a flat spiral. A fine platinum wire is fused into the end and connects with the mercury, its other end being secured to a binding-post. The thermostat is secured in a vertical position to a stand which is placed on the centre of the table upon which the chronometers to be tested are placed. A small platinum wire passes down into the upper end of the thermostat, and is secured at its upper end to a binding-post on the top of the stand.

A delicate and plainly graduated maximum and minimum thermometer is also attached to the stand, and, with the bulb of the thermostat, is placed on a level with the chronometers.

The controlling circuit leads from one pole of the battery to the binding-screw at the top of the stand, from there through the platinum wire, mercury column, and platinum wire to the other binding-screw; thence to the spools of an electro-magnet placed on the small shelf by the automatic valve, and thence back to the battery.

A condenser, or spark-arrester, is placed in the circuit between the binding-posts of the thermostat.

AUTOMATIC VALVE AND CONTROLLING MAGNET.

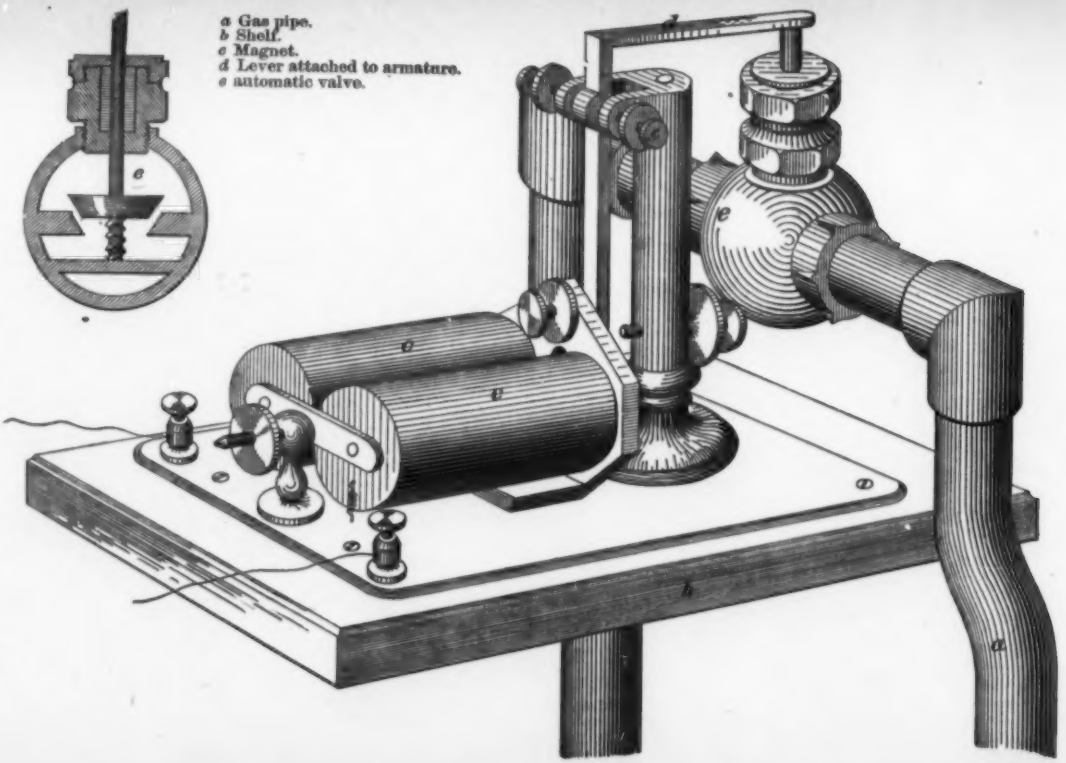
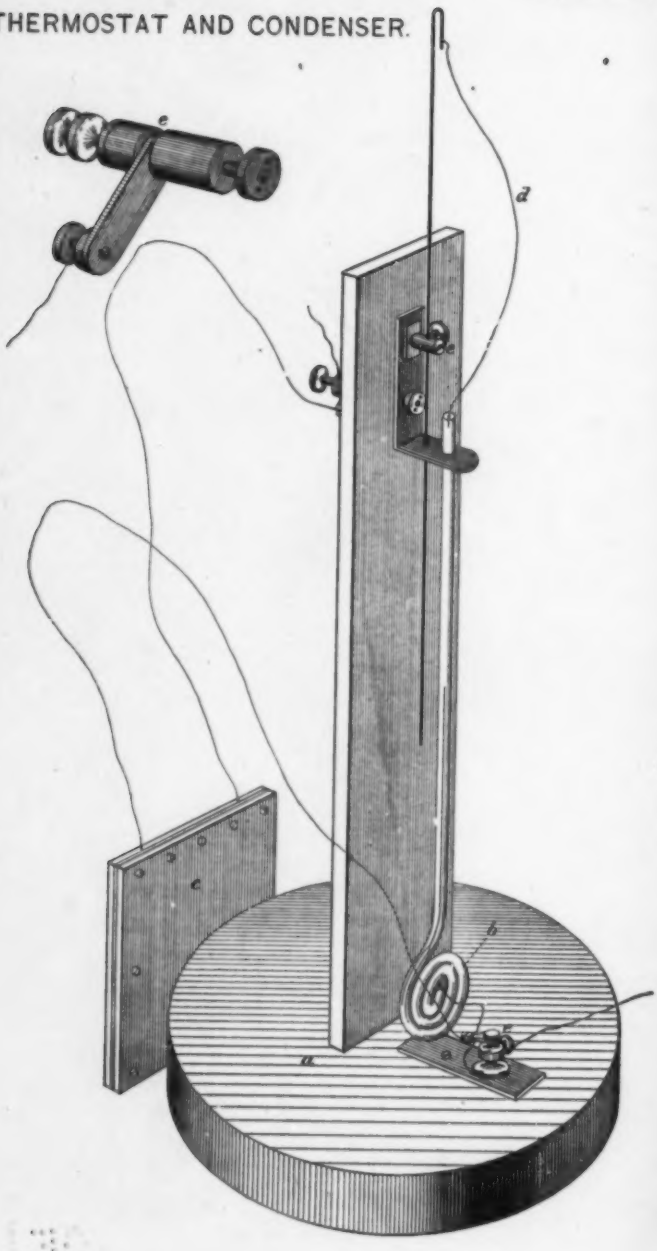


PLATE III.

PLATE IV.

THERMOSTAT AND CONDENSER.



When in use the platinum wire is adjusted so that the end in the tube indicates the temperature at which the room is to be kept, and the small gas jets are lighted. Suppose the temperature of the room to be below that required, the mercury column will not be in contact with the platinum wire, and the circuit will be open. In this condition the valve will be open, gas flowing and burners burning, which will continue until the temperature rises and closes the circuit by contact between the mercury and platinum; this attracts the armature and closes the valve. This continues until the temperature falls enough to break the circuit, when the same action is repeated.

This is found to work in a very satisfactory manner during the six colder months of the year; the temperature of the room is kept within a range of two degrees, and not unfrequently for forty-eight hours within one degree. By covering the circulating coils with large sheets of close wrapping paper, folded in the middle and dropped over the pipes, leaving the bottom open, the range of temperature is decreased about one-half.

The table on which the chronometers are placed is circular, and stands in the middle of the room, with the control and automatic thermometers in its centre. Each chronometer has a separate compartment, large enough to receive the chronometer and leave a space of an inch or more between its case and the walls of the compartment, each compartment being fitted with a separate lid. Holes are bored in the bottoms of the compartments to allow a free circulation of air, and the lids are left open except at the time of comparing, when they are all closed except that of the chronometer under comparison. The object of this is to permit the comparisons by ear to be made more easily.

A hygrometer is used for testing the moisture in the air, and is left in the room only long enough to determine the daily percentage.

All of the chronometers are compared daily between 11 and 11.40 A. M. with the mean time standard clock, and the errors and rates are worked up every seventh day, called term day; from these mean rates all calculations are made. Comparisons are made to the nearest quarter of a second. The temperature is closely observed each day at comparison and recorded for the previous twenty-four hours, by a chronometric thermometer (a chronometer not compensated for temperature), and by self-registering maximum and minimum thermometers.

All chronometers received, either new, or after having been cleaned

and repaired, are placed on trial for six months before their purchase, if new, or before their issue, if old ones. The trials should commence near the middle of summer or the middle of winter in each year, so that the natural temperatures of both the extremes can be used as well as artificial ones.

All chronometers on being placed on trial have the tops of their boxes removed for convenience in comparing, and in order to make them more sensitive to the surrounding temperature. They are examined to see that they fit properly in their gimbals, work perfectly free and without jar, and hang with their faces horizontal.

Some time during the cooler months of their trial they are placed in the temperature room for about fifty days, during which time they are given two tests at three different temperatures, one set going from a lower to a higher, and the other from a higher to a lower temperature, always beginning with one extreme and ending with the same. By this means the effect of time on the rate is eliminated.

Any three temperatures between 45° and 90° Fahr. may be used, as between these points with the ordinary chronometer the changes of rate, owing to temperature alone, are proportional to the squares of the differences of temperature from the temperature of compensation, or fastest running. Fifty-five, seventy, and eighty-five degrees are good temperatures to use, as between these extremes are included all the temperatures through which chronometers will pass in ordinary navigation. These temperatures need not be equidistant, as is the case in Hartnup's method, but may be taken as most convenient.

Suppose we begin this test with 55° as the lowest temperature. The chronometers are placed in the room with the temperature at 52° or 53° for a day or two, when it is raised to 55°, and kept so for a term of seven days; it is then raised slowly to 70° and allowed to remain a day or two at that point before beginning the term at that temperature. After seven comparing days at 70°, the temperature is raised slowly to 85°, and allowed to stand a day or two, and then a seven day term is noted as before. The temperature is then raised to about 90°, allowed to stand a day or two, then lowered to 85°, and the same tests made again, only in reverse order.

Great care must be exercised, especially in lowering the temperature, to keep the hygrometric state of the air in the room about the same, and in no case to allow it to approach saturation. At each change of temperature a day or two is allowed the chronometers in

PLATE V.

CHRONOMETER TABLE AND THERMOSTAT.

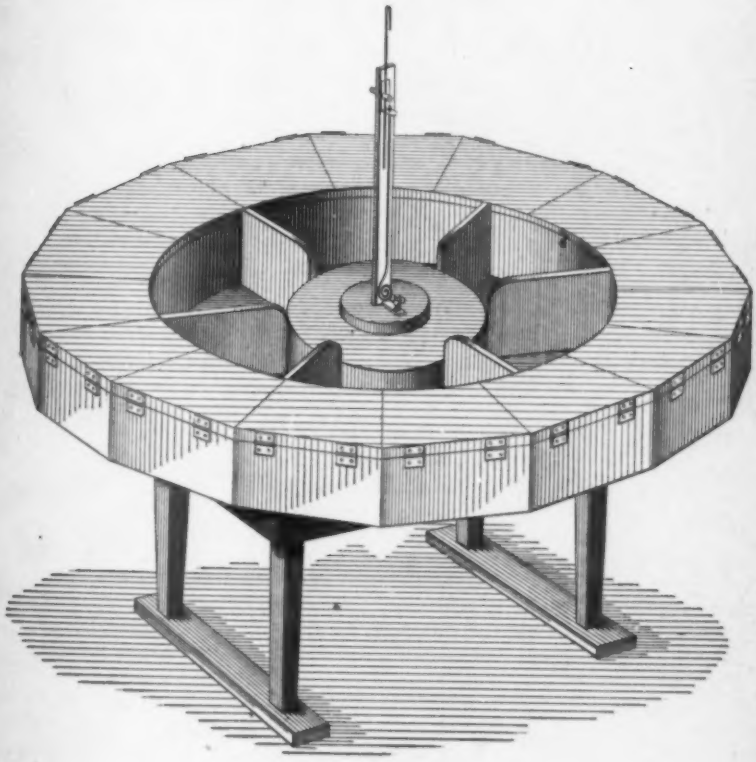
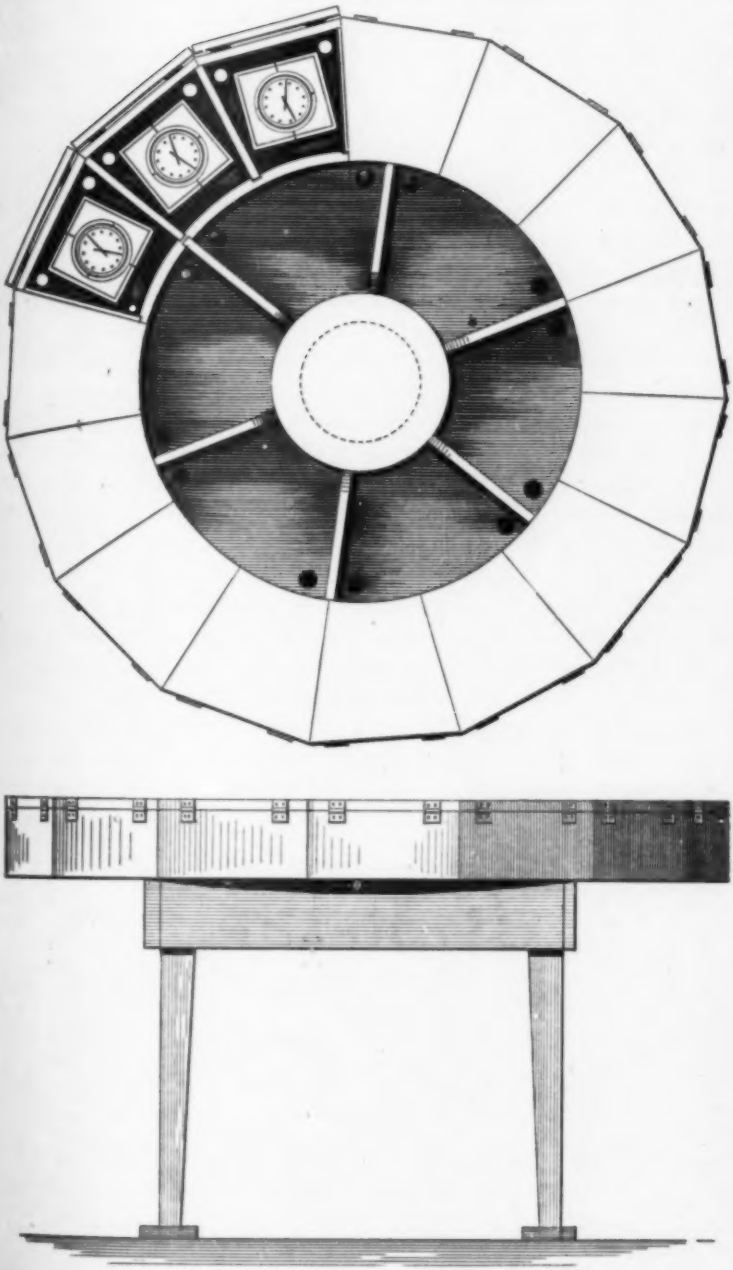


PLATE VI.

CHRONOMETER TABLE.



which to settle to their new rates before beginning the term. Some appear too sensitive and overreach themselves, as it were, gradually falling back; others appear too sluggish, reaching their new rates only after standing a time, while others note the change at once.

In making the second test, the exact temperature used in the first may not be obtained, in which case use the mean of the two temperatures as well as the mean of the two rates for calculations.

All chronometers without auxiliary compensation run fastest at some one temperature, which we shall call the temperature of compensation; this should be the mean temperature to which they will be subjected in actual use, and for navy chronometers it is about 69° Fahr.

The change of rate owing to temperature is least near this point, and increases, the chronometer running slower as the temperature recedes from it. The rate is the same for an equal number of degrees above or below the temperature of compensation. This change of rate is proportional to the square of the number of degrees from the point of compensation, differing for different chronometers. Beyond the limits of about 45° to 90° the change in rate is greater, and proportional to a higher power than the square.

Let $\theta°$ be the temperature of compensation; r the rate at $\theta°$; z the temperature constant, or change of rate owing to temperature at one degree from θ; θ' any other temperature, and r' the rate at $\theta'°$.

Then
$$r' = r + z(\theta - \theta')^2 \qquad (1)$$
which is the general equation for the effect of temperature alone.

Let d, e, and f be the mean temperatures obtained in the temperature room, and a, b, and c the mean rates at these temperatures respectively. Then,

$$a = r + z(\theta - d)^2$$
$$b = r + z(\theta - e)^2$$
$$c = r + z(\theta - f)^2.$$

Whence,
$$\theta = \frac{(b-c)(d^2-e^2) - (a-b)(e^2-f^2)}{2[(a-b)(f-e) - (b-c)(e-d)]} \qquad (2)$$

$$z = \frac{(a-b)}{(\theta-d)^2 - (\theta-e)^2} = \frac{(b-c)}{(\theta-e)^2 - (\theta-f)^2} \qquad (3)$$

$$r = a - z(\theta-d)^2 = b - z(\theta-e)^2 \qquad (4)$$

$$rn = r + z(\theta - \theta n)^2 \qquad (5)$$

These quantities differ for every chronometer, but θ and z remain practically constant for the same chronometer as long as its compen-

sation remains unchanged; and the chronometer may go through the hands of its maker, be cleaned, oiled and have minor repairs, and yet these constants remain the same. As a fact, in cleaning and repairing chronometers the makers seldom change the temperature compensation unless it is known to be excessive; r is variable and changes with time and conditions which will be treated of hereafter.

The first chronometers were placed in the temperature room about February 1, 1883, and the results of some of the best were as follows:

MEAN DATE, *Feb.* 26, 1883.

No. 729 *Negus.*

Mean temperatures and rates going from a low to a higher temperature:

At 56.1°, rate+0.570s. At 68.0°, rate+0.976s. At 83.1°, rate+0.396s.

Mean temperatures and rates going from a high to a lower temperature:

At 56.5°, rate+0.908s. At 68.6°, rate+1.264s. At 83.5°, rate+0.352s.

Means of the above temperatures and rates:

At 56.3°, rate+0.739s. At 68.3°, rate+1.120s. At 83.3, rate+0.374s.

Substituting the means in formulæ (2), (3), and (4), and solving:

$a = +0.739$s. $\quad (b-c) = +0.746$s. $\quad d = 56.3° \quad (f-e) = 15°$

$b = +1.120 \quad (a-b) = -0.381 \quad e = 68.3 \quad (e-d) = 12$

$c = +0.374 \quad f = 83.3$

$d^2 = 3169.69 \qquad e^2 = 4664.89$

$e^2 = 4664.89 \qquad f^2 = 6938.89$

$(d^2 - e^2) = -1495.20 \qquad (e^2 - f^2) = -2274.00$

$(b-c) = +0.746 \qquad (a-b) = -0.381$

$(b-c)(d^2-e^2) = -1115.4192 \qquad (a-b)(e^2-f^2) = +866.394$

$(a-b)(e^2-f^2) = +866.3940$

diff. $= -1981.8132$

$(a-b) = -0.381 \qquad (b-c) = +0.746$

$(f-e) = +15. \qquad (e-d) = +12.$

$(a-b)(f-e) = -5.715 \qquad (b-c)(e-d) = +8.952$

$(b-c)(e-d) = +8.952$

diff. $= -14.667$

2.

$-1981.8132 \div -29.334 = 67.56° = \theta.$

$(\theta - d) = +11.26 \quad (\theta - d)^2 = 126.7876$
$(\theta - e) = -0.74 \quad (\theta - e)^2 = 0.5476$
$(a - b) = -0.381 \quad \div \text{diff.} = +126.24 = -0.00302\text{s} = z$
$(\theta - d)^2 = 126.7876$
$z = -0.00302$
$a = +0.739\text{s} - \text{prod.} = -0.38289\text{s} = +1.122\text{s} = r$
$(\theta - e) = -0.74 \quad (\theta - e)^2 = 0.5476$
$(\theta - f) = -15.74 \quad (\theta - f)^2 = 247.7476$
$(b - c) = +0.746 \quad \div \text{diff.} = -247.2 \quad = -0.00302\text{s} = z$
$(\theta - e)^2 = +0.5476$
$z = -0.00302$
$b = +1.120\text{s} - \text{prod.} = -0.00165\text{s} = +1.122\text{s} = r.$

Substituting the obtained values of θ, z, and r, in formula (5), and solving for every 5°, we have :—

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	−0.414s.	60°	+0.950s.	75°	+0.944s.
50	+0.192	65	+1.102	80	+0.653
55	+0.646	70	+1.103	85	+0.202
				90	−0.400

No. 1220 *Negus.*

Mean temperatures and rates from temperature room :
At 56.3°, rate+0.175s. At 68.7°, rate+0.464s. At 83.3°, rate−0.201s.
$\theta = 67.07°$. $z = -0.00255\text{s}$. $r = +0.471\text{s}$.

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	−0.771s.	65°	+0.460s.	85°	−0.349s.
50	−0.270	70	+0.449	90	−0.870
55	+0.100	75	+0.311		
60	+0.334	80	+0.045		

MEAN DATE, *May* 1, 1883.

No. 1059 *Negus.*

Mean temperature and rates from temperature room :
At 61.5°, rate−0.658s. At 73.0°, rate−0.642s. At 85.1°, rate−1.175s.
$\theta = 67.62°$. $z = -0.00188\text{s}$. $r = -0.588\text{s}$.

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	−1.550s.	65°	−0.601s.	85°	−1.156s.
50	−1.172	70	−0.599	90	−1.530s.
55	−0.887	75	−0.690		
60	−0.697	80	−0.876		

No. 221 Bond.

Mean temperatures and rates from temperature room:

At 61.5°, rate—2.096s. At 73.0°, rate—1.820s. At 85.1°, rate—1.765s.

$\theta = 81.81°$. $z = -0.00083$s. $r = -1.755$s.

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	— 2.880s.	65°	— 1.989s.	85°	— 1.766s.
50	— 2.595	70	— 1.871	90	— 1.810
55	— 2.351	75	— 1.793		
60	— 2.150	80	— 1.758		

No. 505 Bond.

Mean temperatures and rates from temperature room:

At 61.5°, rate+0.626s. At 73°, rate+0.983s. At 85.1°, rate+0.378s.

$\theta = 71.77°$. $z = -0.00343$s. $r = +0.988$s.

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	— 1.470s.	65°	+ 0.831s.	85°	+ 0.388s.
50	— 0.637	70	+ 0.977	90	— 0.152
55	+ 0.023	75	+ 0.952		
60	+ 0.513	80	+ 0.756		

These rates may be tabulated for every 5° as above; or if the value of z, on which the change depends, is large, for every degree. It is, however, more convenient to have them in the form of a curve, from which the rate at any temperature can be taken at a glance.

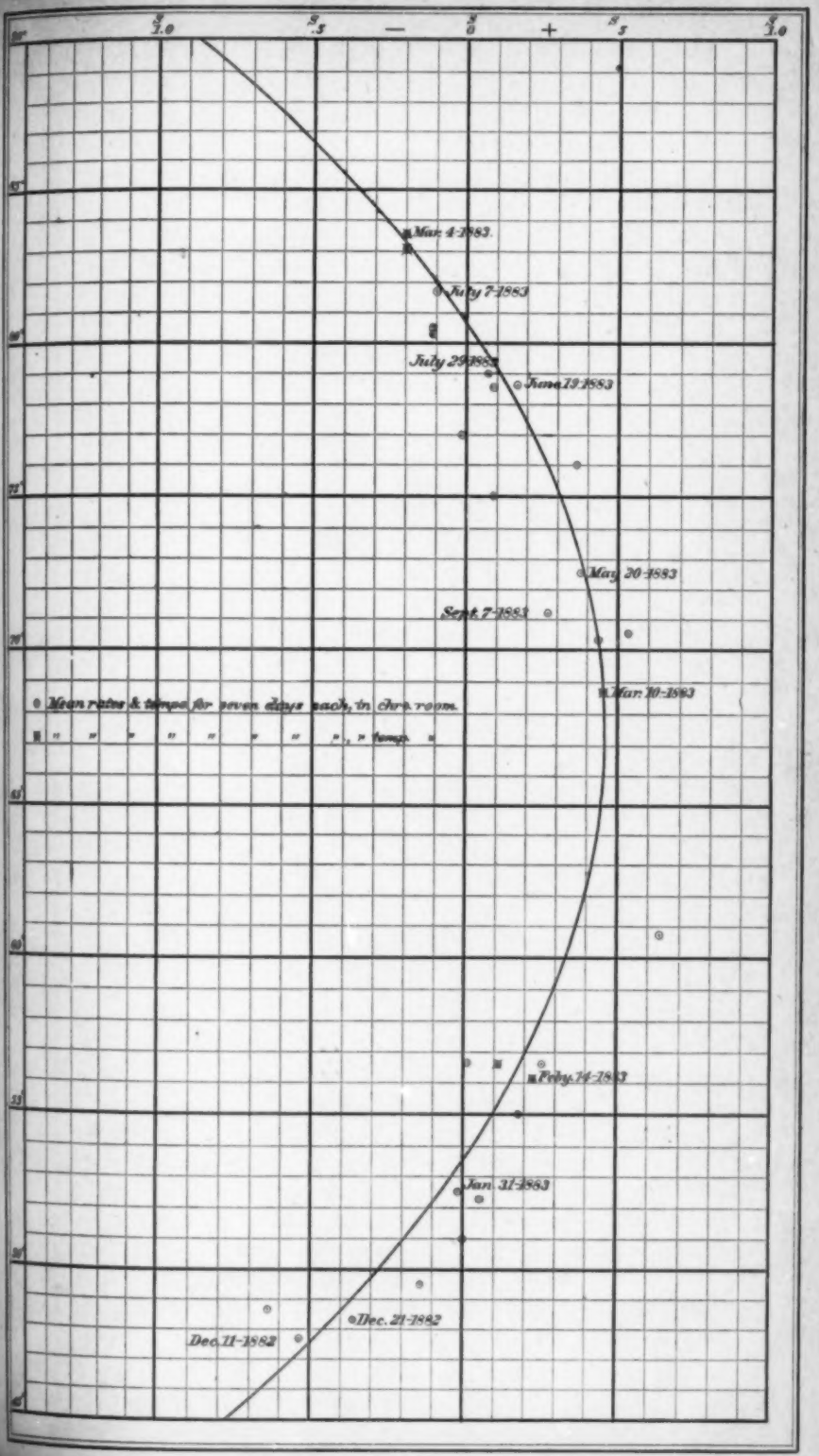
Take a sheet of profile or other paper, evenly ruled both ways, plate VII. Let the horizontal lines represent degrees, numbered at the left hand, and the vertical lines tenths of seconds, numbered at the top. Draw a distinctive vertical line, say in red, to represent the zero rate, and let all rates to the right be *plus* or gaining, and all to the left be *minus* or losing. Plot the rate for every 5° as calculated, by making a dot on the temperature line directly under the rate as shown at the top of the card. Draw a free curve passing through each of these points, or, what is better, bend a spline until it is tangent to each of these dots, and rule the curve.

The intersection of this curve with any temperature will be the mean rate for that temperature and is read from the top of the card directly over the intersection.

The position of the zero line will vary with the chronometer, depending on the size and sign of its rate.

Each chronometer running at the Observatory has a card with its curve constructed and rates plotted up to date, so that in the selec-

Chro. No. 1220 Negus. Curve and Rates, Nov. 25, 1882, to Sept. 17, 1883.



tion of a chronometer for any purpose, its record since it was last cleaned can be seen at a glance, and the one selected whose compensation is most suited to the temperature in which it is to be used. When the chronometer is issued, a copy of the card goes with it, showing the curve and last rates at different temperatures.

The rates are to be kept plotted during the cruise and the cards returned to the Observatory with the chronometers.

This curve being a parabola, the general equation $y^2 = 4ax$ satisfies all its conditions.

Substitute for y, $(y - b)$ and for x, $(x - c)$;

Whence $$y^2 - 2by - 4ax = -b^2 - 4ac = c' \qquad (6)$$

$$\frac{1}{4a} = \frac{x}{y^2} \qquad (7)$$

$$xn = \frac{1}{4a} v^2 n \qquad (8)$$

From the record of No. 729 Negus, substitute the several values of x and y in (6), letting 68.3° be the axis of x, and 0 seconds the axis of y, and solve for the coordinates of the vertex.

$$x = +1.122s = r, \text{ and } y = -0.74° \quad \therefore \theta = 67.56°.$$

With coordinates passing through the vertex, from (7),

$$\frac{1}{4a} = -0.00302 = z.$$

Substituting these values in (8) we have,

Temp.	Rate.	Temp.	Rate.	Temp.	Rate.	Temp.	Rate.	Temp.	Rate.
45°	−0.414s.	50°	+0.192s.	55°	+0.646s.	60°	+0.950s.	65°	+1.102s.
70°	+1.103s.	75°	+0.944s.	80°	+0.653s.	85°	+0.202s	90°	−0.400s.

The same are obtained by (2), (3), (4), and (5).

The more accurate the observations for rate and temperature, the more accurate and satisfactory, of course, will be the result; but with the present accurate methods in general use for determining longitude, and the additional facilities for rating by telegraphic signals, time balls, &c., (2), (3), (4), and (5) can be used with close approximation on board cruising vessels where no temperature-rate has been furnished, or for testing that already given.

For this purpose rates should be obtained as frequently as possible, the observer noting carefully the temperature of the chronometers between the observations; for this purpose no chronometer box should be without a good maximum and minimum thermometer. Having obtained a sufficient number of rates at different temperatures, say eight or more, divide them into three sets, putting in each

set, two or more taken at nearly the same temperature. Reject those that differ too greatly from the average temperature of their set, remembering that the change of rate is as the square, and not directly as the difference of the temperature. Reject also any rate that is phenomenal, for the best chronometers will sometimes run wildly for a term or two without apparent cause and then come back again to their usual rates.

Take the mean rate and mean temperature of each set and substitute them in (2), (3), and (4). A convenient way to form the sets is to plot the rates on the card as before described, then to combine in groups those of nearest temperatures and rates.

Chronometer No. 1262 Negus, Plate VIII, was worked up and plotted in this way. It was running at the Observatory from January 6, 1880, to August 18, 1881, when it was issued. It was again returned to the Observatory, March 1, 1883, having been in service afloat. Its record is as follows:

Mean date, April 11, 1880.

	Temp.	Rate.		Temp.	Rate.		Temp.	Rate.
Jan. 16,	59.0°	—1.448s.	Mar. 6,	66.7°	—0.936s.	July 4,	82.5°	—2.180s.
Feb. 15,	56.0	—1.670	Apl. 5,	63.7	—1.145			
Feb. 25,	59.5	—1.394	Apl. 15,	64.5	—0.979	July 14,	84.3	—2.341
Mean,	58.2°	—1.504s.		65.0°	—1.020s.		83.4°	—2.260s.

$\theta = 68.07°$. $\quad z = -0.00550$. $\quad r = -0.968s$.

Mean date, April 29, 1881.

	Temp.	Rate.		Temp.	Rate.		Temp.	Rate.
Jan. 20,	56.5°	—1.694s.	Apr. 10,	71.3°	—0.762s.	July 19,	83.2°	—1.910s.
Jan. 30,	56.6	—1.733				Aug. 8,	82.2	—1.936
Apr. 10,	56.0	—1.297	May 10,	68.9	—0.709	Aug. 18,	81.1	—1.802
Mean,	56.4°	—1.537s.		70.1°	—0.735s.		82.2°	—1.883s.

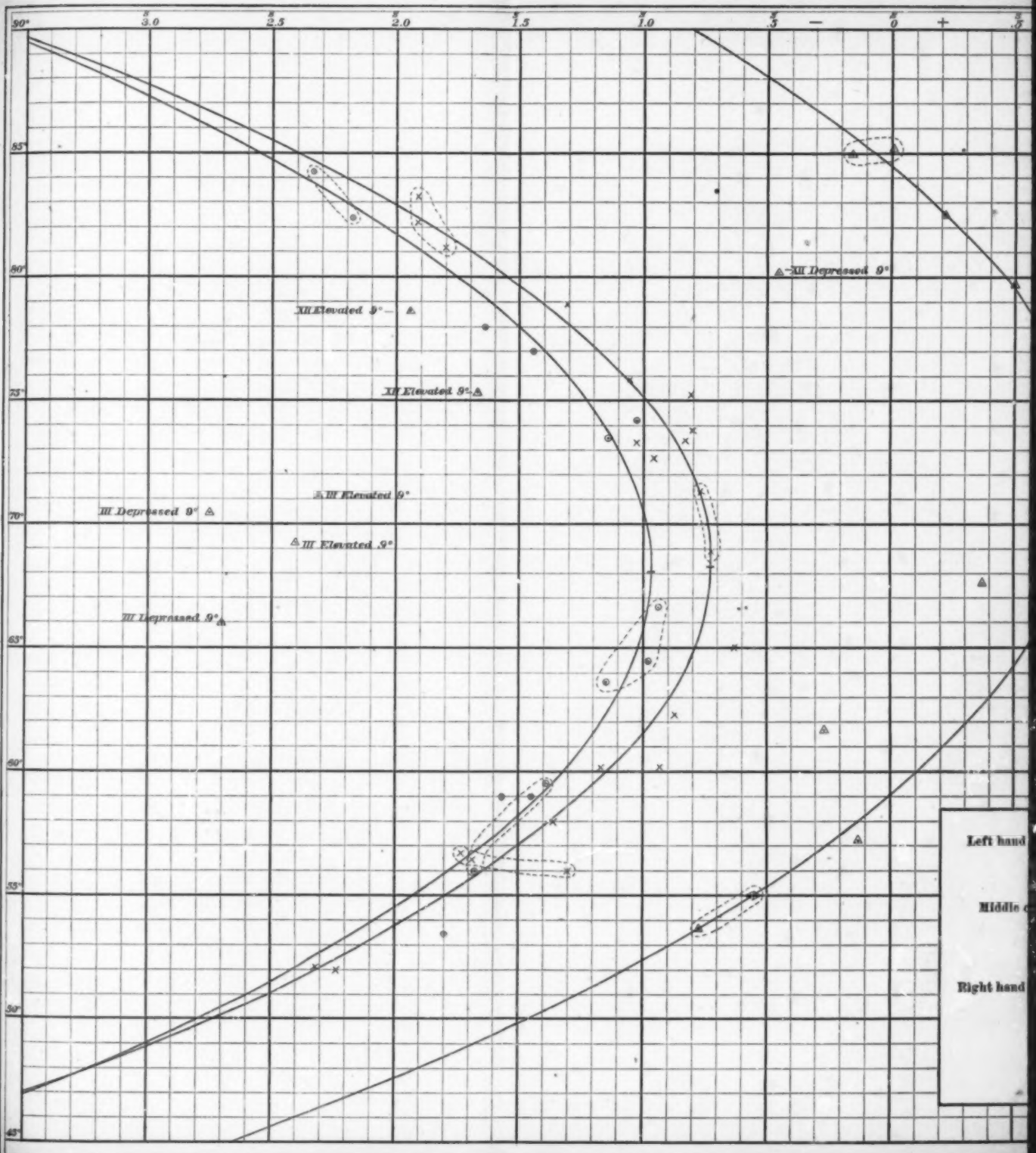
$\theta = 68.31°$. $\quad z = -0.00604$. $\quad r = -0.716s$.

Mean date, April 17, 1883.

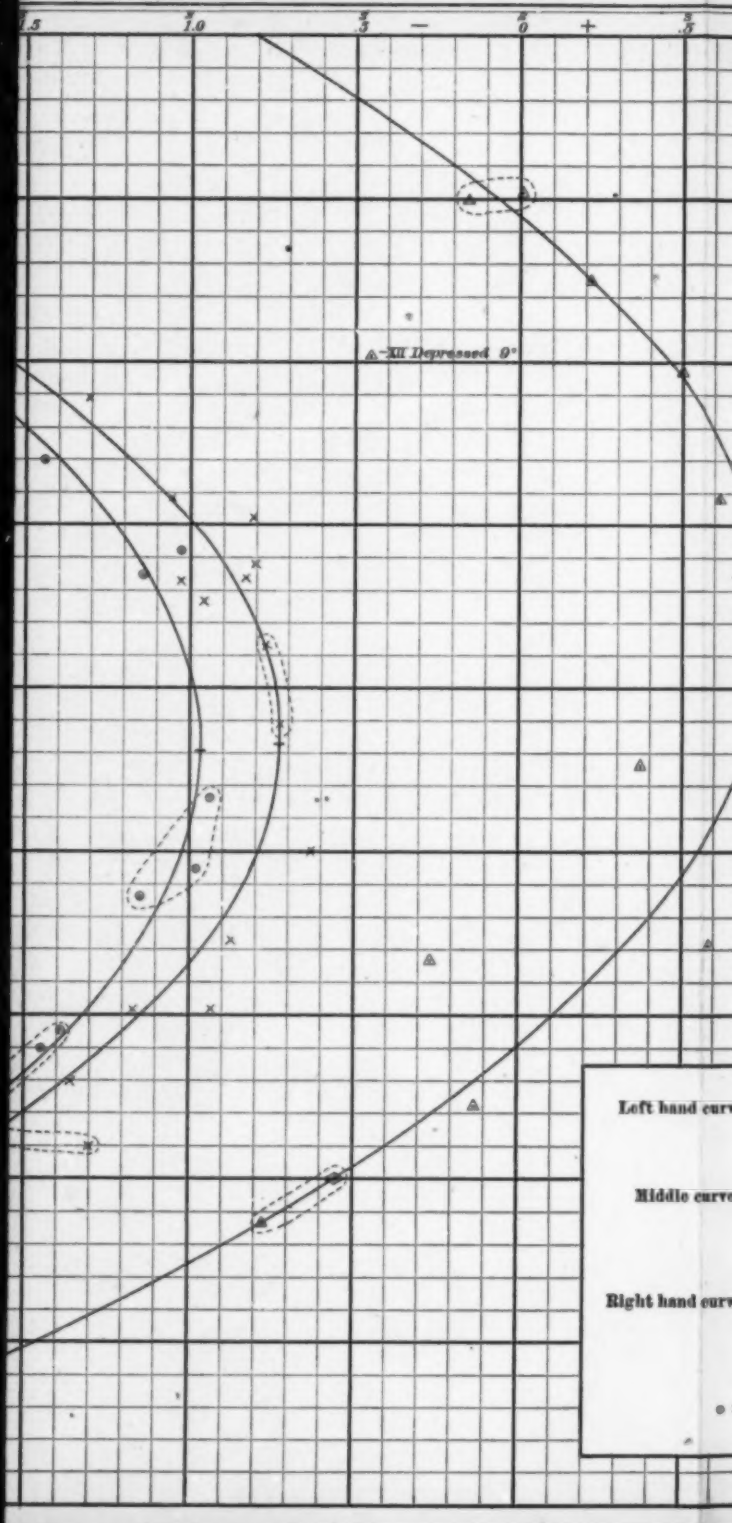
	Temp.	Rate.		Temp.	Rate.		Temp.	Rate.
Mar. 11,	53.8°	—0.768s.	Apr. 21,	73.0°	+0.707s.	Apr. 29,	85.2°	+0.011s.
Mar. 31,	55.0	—0.562	May 19,	72.9	+0.866			
Apr. 6,	55.0	—0.550	June 5,	73.6	+0.696	May 8,	85.0	—0.149
Mean,	54.6°	—0.627s.		73.2°	+0.756s.		85.1°	—0.069s.

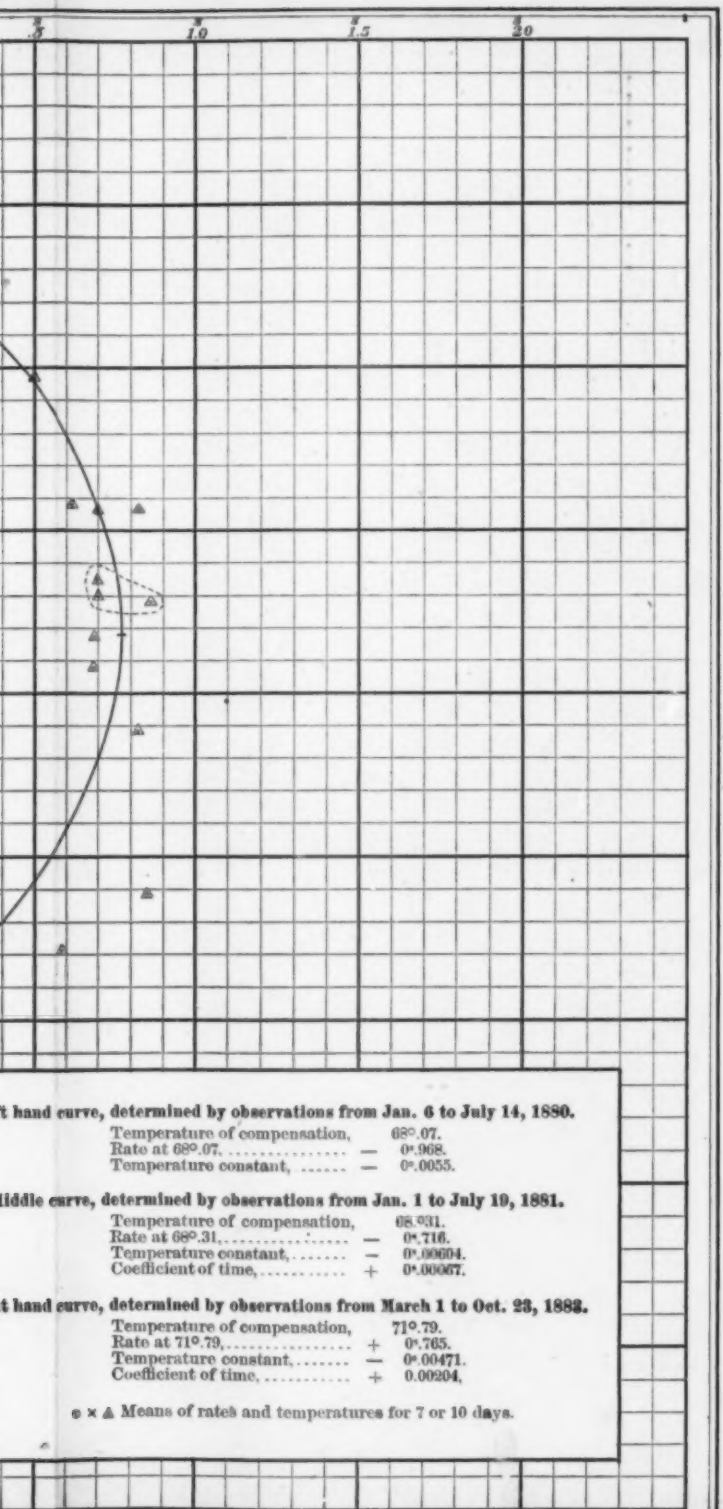
$\theta = 71.79°$. $\quad z = -0.00471$. $\quad r = +0.765s$.

Chro. No. 1262 Negus. Temperature Curves for 1880, 1881 and 1883



ro. No. 1262 Negus. Temperature Curves for 1880, 1881 and 1883.





t hand curve, determined by observations from Jan. 6 to July 14, 1880.

Temperature of compensation,		68°.07.
Rate at 68°.07,	—	0ˢ.968.
Temperature constant,	—	0ˢ.0055.

liddle curve, determined by observations from Jan. 1 to July 19, 1881.

Temperature of compensation,		68°.31.
Rate at 68°.31,	—	0ˢ.716.
Temperature constant,	—	0ˢ.00604.
Coefficient of time,	+	0ˢ.00067.

t hand curve, determined by observations from March 1 to Oct. 23, 1882.

Temperature of compensation,		71°.79.
Rate at 71°.79,	+	0ˢ.765.
Temperature constant,	—	0ˢ.00471.
Coefficient of time,	+	0.00204.

⊕ × △ Means of rates and temperatures for 7 or 10 days.

The above data were taken from the records of the chronometer, without application of the effect of time, running in natural temperatures; the highest temperature for 1883, however, was obtained in the temperature room. The sets were selected by grouping the rates near the same temperature, the dotted lines showing the groups used, and the dots ⊙ × △, the mean rates and temperatures, each for ten days, during the time under comparison. The values of θ and z remain practically constant for 1880 and 1881, and change but little for 1883. A portion of this change may be attributed to the coefficient of time, which has not been considered.

r changes more or less with time in all chronometers, generally increasing if its sign is +, and decreasing if it is —. That is, from the time of cleaning, chronometers, as a rule, run faster as their age increases. This is especially so with new chronometers, which sometimes take two or three years to settle down to a steady rate. Not unfrequently do they gain, in the course of a three years' cruise, three or four seconds on the rates given them when issued. This change is gradual, and the daily acceleration or retardation is the coefficient of time.

Let T be the date at which the rate at a given temperature is r; T_1 any other date at which the rate at the same temperature is r_1; $T_1 - T = t$, the elapsed time, and g the coefficient of time.

Then
$$g = \frac{r_1 - r}{t} \tag{9}$$

And (1), the general equation of the chronometer, becomes

$$r' = r + z(\theta - \theta')^2 + gt \tag{10}$$

With No. 1262 Negus, from April 11, 1880, to April 21, 1881, $g = +.00067$; and from April 21, 1881, to April 17, 1883, $g = +.00204$. Owing to the change of θ and z the latter value of g was a little larger for temperatures above 70°, and a little smaller for temperatures below 70°.

In the ordinary uses of the chronometer for navigation purposes, the last term, gt, of equation (10), may be, and should be, omitted, as the value of g may change with time, and its use would indicate a greater degree of accuracy than would actually be obtained. Again, its value is always small, and the accumulated error from its rejection would come within the probable error of observation when ratings are frequent. It should, however, always be used in the establishment of longitude by meridian distances, and in other work where back calculations are made.

The temperature corrections should be used at all times, more especially when changes of temperature are frequent and extreme, and in making long voyages. A change of a few degrees in the higher or lower temperatures will change the daily rate one or more seconds, soon making the accumulated error amount to several miles in longitude. It is well to keep the chronometer record up for temperature even while lying in port, as it gives the navigator a knowledge of how it is running, and shows him what reliance he can place upon it at sea. By reference to Plate VIII, it will readily be seen what the effect would be on the rate of No. 1262 Negus were it rated in about 68°, and then taken into a temperature of either 55° or 80°, as often occurs.

Having determined the curve, on obtaining a rate at any subsequent time, if the rate does not plot on the curve, the difference will be a constant to be applied to all rates taken from the curve at different temperatures.

Great care should be taken when chronometers are suspended in their gimbals that they swing perfectly free, but without play enough to give them a jar; and the gimbals should be so adjusted that the chronometers will always hang with their faces level.

Nos. 725 and 1262 Negus, both running very regularly and adhering closely to their curves, were canted 9°, first with the XII down, then with the VI, IX and III down successively, leaving them two terms of seven days in each position, and placing them level again for two terms between the successive changes. They both lost on their level rates, varying from five-tenths to three seconds, and were more or less irregular; but when placed level again they each time came back to their regular rates, running a little irregularly at first.

Their mean rates reduced to a temperature of 70°, were as follows:

No. 725 Negus.

Face level, +0.72s; XII down, — 2.18s; level, +0.77s; VI down, —1.27s; level, +0.78s; IX down, +0.17s; level, +1.01s; III down, — 1.21s.

No. 1262 Negus.

Face level, +0.74s; XII down, —0.20s; level, +0.82s; VI down, — 1.70s; level, +0.75s; IX down, — 2.36s; level, +0.84s; III down, — 2.65s.

The above changes are not excessive for chronometers slightly canted, and the cant is what would take place were the screws in one of the adjusting slots of the gimbals to become loose, allowing the bowl to slide to one side or the other.

At some time during the trial, after the chronometers have passed through the temperature test, and their curves have been determined, they are rated for one term of seven days each with the XII of their faces North, South, East, and West, successively, as a test for polarity; and should any evidences be found, they are again put through the different positions to make sure that the irregularities are not merely coincidences. Chronometers having actual polarity are at once rejected.

The chronometers are relatively placed after trial by the trial number, which is: Trial number $= (69° - \theta) + 1000\, z^2 + 10\, v^2$, in which 69° Fahr. is the temperature at which the chronometers should be compensated to have their fastest rates, and it is obtained by taking for a number of years the mean of the chronometer boxes of several vessels of the navy serving on different stations. z is the temperature-constant, and v the arithmetical mean of the five greatest variations of the mean rates from the curve as determined by formula (5).

$(69° - \theta)$ should in no case exceed 10°, except in chronometers compensated for special purposes, and it should be allowed to approach 10° only when z is very small, making the curve nearly a straight line. z should in no case exceed .006, and should be allowed to approach it only when $(69° - \theta)$ is very small, thus placing the large variations of rate, due to temperature, in the extremes to which the chronometers would seldom be subjected. v should in no case exceed 0.5os, making due allowance for coefficient of time, especially in new chronometors.

Chronometers failing to pass the required trial are returned to their makers, and rejected, if new and for purchase; but if old ones having been cleaned and repaired, they are to be recompensated free of charge and returned for a new trial.

Chronometers for service are selected with a view to the temperature in which they are to be used. Those for warm climates should have their point of compensation highest, and those for cold climates the reverse. Those to be used in both cold and warm climates should have their temperature-constant small; and in all cases the

smaller the value of z, the nearer the curve will approach a straight line and the better will be the chronometer, all other things being equal. On being issued, chronometers are transported by hand direct from the Observatory to their destination while still running, and are handled with the greatest care. For transportation they are taken from their gimbals, wrapped closely in paper and placed level in a basket of cotton, cushioned around the edges and from each other, but not tightly packed. They are delivered to the navigation officer of the navy yard or of the vessel, as the case may be, when the supervision of the Observatory ceases until their return. Their boxes are enclosed in the transporting cases, neatly crated and sent as freight.

In transportation the principal things to be guarded against are circular motion and placing them in any other position than a level one. If their error and rates are to be carried on in transportation, a maximum and mimimum thermometer should be packed in the basket as near as possible to the chronometers to obtain their mean temperature *en route*.

NAVAL INSTITUTE, ANNAPOLIS, MD.

FEBRUARY, 1884.

CHARTS AND CHART MAKING.

BY LIEUTENANT JOHN E. PILLSBURY, U. S. N.

The question of aids to safety in navigation is of great importance to a very large portion of mankind. The merchant who is interested in the vessel or the cargo ventures his capital; the passengers, who as a rule know the least of the dangers to be overcome, and who are obliged to have faith in the ability of the officers in charge and in their appliances, are risking their lives; and the officers, on whom the whole responsibility rests for the safety of the property under their charge, as well as for the lives of those on board, are staking their reputations as well as their lives every time they get underway.

Without a chart of some sort the question of navigation would be reduced to a matter of considerable difficulty and great hazard; and in this day of high speed, quick sales for early cargoes, increase of pleasure-travelling, and efforts for the repeal of compulsory pilot laws, it is imperative that the piece of paper on which are depicted the shore-line and contour of the bottom shall be as nearly true to nature as it is possible to make it, and should show everything that can in any way assist in bringing the vessel safely into port.

As a rule, from the beginning of chart-making, governments have assisted and fostered work of this kind; but it is only in comparatively recent times that governments have engaged in a systematic collection of data, and an embodiment of the data on well-digested schemes of charts embracing the whole world.

There may be some present who are not wholly familiar with the methods which are at present in use in the Coast Survey in preparing the charts for issue from the beginning. At the risk of repeating a story familiar to some, I would like to relate the various steps in chart-making for the benefit of the others. The primary triangula-

tion of our own coast has been practically finished, and the secondary triangulation nearly so. As the secondary triangulation is carried on, the topography is executed according to schemes drawn up by the Superintendent. The Hydrographic Inspector, in consultation with the Superintendent, receives directions as to the localities of the proposed hydrographic work, and then lays out the scheme of projections for each party according to the nature of the work. The draughtsmen in the office prepare the projections according to this scheme, and the chiefs of the hydrographic parties eventually receive them, together with descriptions of triangulation points, bench-marks and detailed instructions from the Hydrographic Inspector.

Upon the conclusion of the survey the projections are returned to the office, showing the fixed positions on all the lines of soundings, appropriately lettered and numbered, together with sounding-books, showing the soundings and times, and the angles taken with them; angle-books, showing the angles used to cut in hydrographic signals from the triangulation points; tide-books, showing the reading of the tide-gauge during the progress of the survey, and, lastly, sailing directions, or a description of points of interest developed during the work. Draughtsmen attached to the office of the Hydrographic Inspector then verify the positions, plot the soundings, and, after the finished sheet is registered, the draughtsmen of the drawing division make a reduction of it for the engraver, on the exact scale to be used for the finished chart, which is verified by the Hydrographic Inspector by comparison with the original. In the meantime a project has been decided upon, showing the limits of the proposed chart; the topography has been reduced and a plate has been prepared ready for the engraver. As a rule, engravers have two plates on hand at once, so that while one is being proofed, or is waiting for additional work, or is delayed from any cause, the other may be taken up and no time be lost. As the plate approaches completion in hydrography and topography, the magnetic variation is ascertained for the probable time of issue; the light-house table prepared, and the "aids to navigation" are obtained from the Light House Board, and the title and notes decided upon.

When the plate is finished it goes to the electrotype department to be duplicated. One plate will stand only about 1200 or 1500 impressions, and in order to save cost of reproduction by engraving, the original is duplicated for a printing-plate and then stowed away. The electrotyper first cleans the plate with potash,

then coats it with the thinnest possible film of silver to prevent the original from adhering to the alto. It is then placed in a frame in a vertical vat holding a solution of sulphate of copper, and is connected with a battery; copper is slowly deposited upon its face for a day or two. The deposit in a vertical vat is the result of very slow action and presents a smooth and even surface all over the face of the plate.

The plate is next placed in a horizontal vat, and the process of depositing the copper is proceeded with more rapidly. It is daily removed and weighed to ascertain the amount it has received, and the protuberances which form on the back are filed down to make a smooth surface. After a few days, when it has received a sufficiently thick coating, it is removed, and it then appears like a single, thick plate, as the deposit and the original plate are joined at the edges. The edges are filed and the plates separated, the deposit being in alto-relievo. The same operation is repeated, using the alto on which to deposit, and the result is an exact duplicate of the original.

About thirty pounds of copper are deposited for a large-sized alto, and fifty pounds for a basso. When the life of this basso is gone, the alto first obtained is used to produce another basso, and so on for perhaps five or six times, or until the alto is used up, when another strong one must be obtained from the unused original basso.

The question of fine printing is almost, if not quite, as important as that of fine engraving. It is almost impossible to obtain a plate of uniform thickness, and as the rolls of the printing press do not allow for irregularities, except to a small degree, the impress will show strong at the thick, and weak at the thin parts. The printer first lines up the rolls to the average thickness of the plate, and takes an impression. He then cuts out pieces of paper of the shape of the weak parts and puts them under the back of the plate, and runs it through again. This time it looks better, but he continues cutting out pieces and pressing up more and more upon the back of the plate at the faulty places, until he has a perfect proof. After the day's printing is completed, the charts are dried and then placed in a large press and subjected to a pressure of about two hundred and fifty tons, which takes out all the irregularities and forces the ink into the paper so that it will not readily rub in use.

Dry printing is impossible with an engraved plate, and wetting the paper is open to serious objection because of the shrinkage in drying. The paper supplied from France shrinks the least and also the

most regularly in all parts, the shrinkage being only 1 per cent. with the grain, and 1½ per cent. across; but this paper is of very short fibre and breaks and tears even with the greatest care, and it is very expensive. American paper shrinks unevenly, the shrinkage being about 1 per cent. with, and 2½ per cent. across the fibre; it is, however, better by far than the French paper for use at sea. Bond paper is the toughest and cheapest, but it shrinks so unevenly that it is not advisable to use it for any large charts.

I come now to the question, very important to the chart-maker, and more so to the navigator—that of doubtful dangers and positions. It may be said that, except along the coasts of the chief civilized countries, almost all positions are doubtful; and the dangers in mid-ocean whose positions or existence are not determined number thousands. Upon examining almost any general chart one is struck with the multitude of interrogation marks and other expressions of doubt; and upon examination of the data relating to these presumed dangers, one is astonished at the little knowledge we have of a vast number of them. Before the invention of chronometers, the early navigators, knowing nothing about currents and not reckoning their leeway accurately, obtaining their longitude only by their run, and their latitude by observations with the crudest instruments, have handed down to posterity the accounts of their voyages with remarks like the following: "Landed on the shore of a beautiful island, about 1000 leagues from the coast of New Spain, and in latitude by the sun of 20 degrees south." The latitude might be in error a degree at least, and the longitude half a dozen. Where the descriptions are full, later explorers have been able to recognize them. Some few, however, of those not recognized still have a place on comparatively late charts; in one instance, with the remark "Not seen since 1695." Coming down to more recent dates, when watches and poor chronometers were used, the positions given are of little value except to confirm the existence of a danger.

There are three prominent kinds of error that come to our notice: inaccurate observations, discrepancies in the longitudes of the charts of various countries, and typographical or clerical mistakes. I will here consider the second of these, discrepancies of longitude, leaving the first to be taken up later on.

The charts of the East India archipelago, by the British Admiralty, differed from those of the Netherland government, until within the last decade, by five or six, or in some instances by as much as ten,

minutes in longitude. Within the last three or four years, indeed, the charts of Gaspar strait, by the U. S. Hydrographic Office, differ from the British Admiralty by 1′45″, and from the Netherland charts by over 1′25″. A shoal reported in lat. 3° 00′ 00″ S., long. 107° 15′ 00″ E., was placed on the English chart S. 16°, E., 10 miles distant from Shoalwater island, and on our own S. 7°, E., 9¾ miles distant. A captain discovering a shoal takes bearings, pricks off its latitude and longitude from his chart, and sends the position to the nearest newspaper. At last it reaches the various hydographic offices and appears on one chart southeast of an island, on another south, and on a third still more to the westward. The Scoresby shoal was reported by a captain, who gave good bearings of prominent points which he said plotted on his chart within 30″ of his position by observation. Could we but find the chart he used we too might see the same; but unfortunately, on all authoritative charts, the bearings plot some eight miles away from the position by observation, and so the shoal appeared on our charts in both positions.

It sometimes happens, however, probably through neglecting to keep a systematic record in past years, that even where the position was given at which the chronometer was rated, the longitude of the danger has not been changed with that of the point on which it depended. The Dawson shoal in the Java sea was reported to be in latitude 4° 42′ S., and longitude 117° 05′ 15″ E., depending upon the east point of Pandita island, which was in longitude 115° 40′ 00″ E. The longitude of this island has been corrected to 115° 35′ 30″ E., but the shoal still remains on the charts in the position originally given. This shows the absolute necessity of a system of tabulated records, showing not only the longitude on which each danger depends, but also all the dangers whose positions depend on any prominent point of doubtful longitude. When a correction is made in the position of the primary, as in the case of Pandita island, if we refer to the record, all the secondary positions can be changed without leaving it to some chance investigator to discover the mistake.

Clerical and typographical mistakes cause many errors in the positions of dangers. These errors take the form of changed bearings and distances, wrong figures in geographical positions, and also wrong letters denoting the latitude and longitude. Bearings are reversed, so that instead of the island bearing northeast from the shoal, the shoal is placed northeast of the island. Errors often occur from a confusion of the Paris and the Greenwich

meridians; sometimes the difference of longitudes is entirely omitted. An instance of change in the designation of latitude may be mentioned in the case of the Marqueen or Cocos group. In Mr. Findlay's North Pacific Directory we read that Admiral Krusenstern applied the name of Mortlock to a group discovered by a Captain Mortlock, commanding the Young William in 1793, in about latitude 4° 45′ S., and longitude 157° E. In Findlay's South Pacific Directory we find similar mention, except that the date is given as 1795, and the position is slightly different. It seems hardly possible that the Admiral could have applied the same remarks and name to different groups in the same neighborhood, but in different latitudes. Another example of error in typography is shown in the case of a shoal in the Austral group. It was reported by its discoverer as being placed in about longitude 154° West, and it was carefully described. It was originally noticed in the British Nautical Magazine in the latter part of 1846. In one of the early months of the following year the French Annales Hydrographiques published the notice, but gave the longitude as 150° West (of Greenwich); and in both these positions it appeared on the French charts, and also on those of the British Admiralty. A few months later the British Nautical Magazine again published the information, but this time instead of 154° W. it gave 115 04′ W. as the longitude. That mistakes like these should be made seems strange, but it will be thought even more remarkable when I tell you that in each of these reports it was mentioned that the shoal was some two degrees to the WNW¼W. of Remitera island, which, if the geographical position was omitted, would place it approximately in 154° West. The magazines published the reports evidently as so much printed matter, and not as correct nautical information on which the safety of a vessel might depend. No less than three French vessels have searched for the reported shoal in 150° West, their efforts prompted by this misleading information of the publishers of the magazines.

The government of the United States has been the unwitting cause of encumbering the charts with many danger-marks, which may be alluded to as examples of all kinds of errors. By an Act of Congress of August 18th, 1856, any American citizen who should discover an uninhabited island, rock, or key, on which was a deposit of guano, might enter into peaceable possession of it and be allowed to work it. Such island, rock, or key would then become the property of such citizen, and should pertain to the United States, &c.

Up to the year 1869, on the strength of this law, some seventy or more claims were presented and allowed, and so published to the civilized world. Some of these claims were taken from old charts, on which they had been placed by old whalers and others, in the most erroneous positions, the claimants probably never having visited the spots. Some of the locations were from more recent reports of poor navigators who, by careless observations, had mistaken a well-known island for a new discovery. A considerable number simply originated in the misplacement, chiefly by clerical errors, of islands from east into west longitude, or from north into south latitude, or the reverse. Many of the positions were those of perfectly well-known islands, inhabited in some instances by Europeans, and which never, as far as known, had been guano islands. Many were doubtless genuine discoveries, but most of them probably represented simply the claims of speculators who had ransacked charts, old and new, for islands on which guano might be found, hoping that in their own particular case fortune might favor them and bring gold to their coffers. Doubtless their lack of skill was only equalled by their want of principle, and so, in taking off the positions from the charts, they probably changed names and positions.

Another source from which incorrect reports of dangers come—let us hope, however, that the number is small—is the desire of incompetent, negligent, or careless navigators to escape punishment after running aground on a known danger, by reporting it as a new discovery in another position. The Cornelius Haga rock in Gaspar strait is, probably, an example of this. The vessel was lost, according to her captain's report, on a rock about five miles from Leat island, in the fairway, and the captain gave bearings to support his statement. The rock's position was placed on the charts, and many vessels were sent by the British, Netherland, and American governments to locate the danger. The expenditure of time and money must have been very great in hunting for this will-o'-the-wisp. At last the United States North Pacific Surveying Expedition learned from the natives that the wreck was *on* Leat island, instead of five miles from it, and upon examination it was found to be on a reef within a mile of the beach, and one of the anchors marked Haga was recovered. Another example was communicated to me by an officer now on duty here, who, while navigator of the Penobscot, was ordered to obtain a statement of the facts from a captain who said his vessel had struck on a rock in the Arcadine passage at the entrance to Port-au-Prince. On leaving the

ship, after receiving the captain's statement, he noticed a piece of bush hanging from the martingale-stay of the vessel, and as he was pulling away from the ship he quietly secured it. After searching the passage he pulled to the adjacent Arcadine islands, on the course the vessel had taken, and found that everywhere deep water could be carried up to the very beach; upon comparing the piece of bush with those on the island they were found to agree. It is probable that the vessel had run her head-booms into the bushes; but the captain, to save his insurance, and himself from blame, had wilfully falsified facts.

Discolored water is sometimes, though not always, excellent evidence of a shoal. Many patches of discolored water have been reported between the Kermadec group and the Australian coast; at least two surveying vessels, one English and one German, have found in this region many patches of animalculae, which may have given rise to the reports of shoals. One of these patches described by the German surveying vessel Gazelle had at a little distance a light green appearance, as if a shoal, but upon close examination was found to be composed of minute animals connected together, forming a string.

Breakers cannot always be considered as indicating shoal water. How many times in the experience of every officer who has stood a watch, has he been startled by what at first he thought to be a shoal with heavy breakers near the horizon, when there happened to be a heavy combing sea and the sun shone through the clouds occasionally. The sun shining on the crest of a wave, where all around is in the shade, will produce just such an effect, and this has without doubt been the cause of many reports of shoals by unreasoning or uninvestigating captains.

Of inaccurate observation, little can be said. Even the most careful observers may sometimes make mistakes of this kind. How much surveyors and other reliable authorities differ, even in the determination of latitude, will be seen in the consideration of Krakatoa island, which, lying at the southern entrance of Sunda Strait, has recently been submerged by an earthquake. Its peak has been placed by thirteen different observers, all, I think, naval officers, in the following latitudes, the minutes and seconds only being read: 12′05″, 08′00″, 10′00″, 10′09″, 08′03″, 09′00″, 07′00″, 03′00″, 09′42″, 07′59″, 07′10″, 09′11″ and 09′00″, the extremes differing 09′05″. With these differences in latitude, is it to be wondered that errors in the establishment of longitude occur? Yet these errors are at times

so great as to lead one to the belief that they are the result of mere guesswork. It is related of an old commanding officer in times gone by, that noticing on the chart what he thought to be a rock near which the vessel would pass, he told the navigator to have the course changed at once. The navigator replied, "I think, sir, there is not much danger in that rock," and with his handkerchief brushed from the chart the fragment of snuff that had fallen from the old gentleman's beard. We all wish that the charts could be as easily cleared of all doubtful dangers, and commanding officers as easily relieved from the many cares and doubts that they must feel when in their neighborhood. I have heard many adverse criticisms and objections raised against putting on charts these numerous doubtful reports. Many of the reported dangers, without doubt, have an existence only on paper. But who can tell without the strictest search which one shall be retained and which erased? It is a very easy matter to expunge a shoal from a plate; but it may be rather difficult to explain to the captain who has wrecked his vessel on it afterwards that its removal was warranted on sufficient grounds. I would not advocate placing a new report on a chart without a probability that the danger referred to really exists, and that its position is approximately correct. But, once deemed of sufficient importance to be placed on a chart, it ought not to be removed until an exhaustive search has proved its non-existence with almost absolute certainty. The difficulty of proving beyond doubt that a shoal, even in a well-known harbor, does not exist, is very great, as can be shown by many examples. How much more difficult is it to determine this in mid-ocean! The Rodgers shoal in the China sea was searched for during four days, but, although the original report gave bearings of points on shore, and the boats sounded and swept with a chain all around the spot, no danger was found, until when the vessel was about to get underway, a ripple on the water close aboard was examined and found to be over the rock, almost exactly on the intersection of the bearings given. The vessel and her boats had been many times within a very few feet of the rock without having been able to discover any signs of it. The Brilliant shoal, in about latitude 23° south and longitude 170° east, was discovered in 1847 and located. Captain Durhan, R. N., made a careful search for it, running many lines over a surface sixty miles in diameter about the position, without being able to discover any signs of shoal water, although sounding with 250 fathoms of line. This

was thought to be conclusive evidence of its non-existence, and the British Admiralty expunged it from their charts. It was not long, however, before a French and an English vessel reported it as very near the original position given. It was replaced on the chart, and no doubt was expressed as to the fact of its existence and the correctness of the location. Recently, another English vessel has searched for it, but without success, and again it is marked "Position doubtful." Even on our own coast, within the past year, in Long Island sound, a rock has been discovered having over it 10½ feet of water. It was searched for during many days without success; but finally it was discovered when, on getting underway, the centre board of the surveying schooner grazed its surface.

There are many instances where examinations have been made, and the shoal expunged on evidence of non-existence, derived from careful search over large extent of surface, and from frequent soundings with deep-sea lead in two and three hundred fathoms of water. The evidence, as far as the lead is concerned, is really of not much value when we remember how abruptly rocks rise from great depths. The Coast Survey steamer Blake found depths of over 2000 fathoms within 2½ miles of the Bahama banks; and in some places on the line of soundings the inclination was 45°. Small pinnacles are often met with inshore, and sometimes with such inclination that the lead will not rest on their surfaces. One instance of this is met with near Armstrong bay, on the south coast of Australia. The pinnacle has only one fathom over its apex, and presents so small a surface to the waves that the sea rarely breaks thereon, and the lead finds no resting place. Cases of submersion or subsidence are sometimes found. The Gorringe bank was originally reported as having 3½ fathoms of water; but the Gettysburg found 32 fathoms to be the least depth. Broken coral and shells and well-rounded pebbles were brought up, indicating that erosive wave-action had at one time exercised its influence on the summit of the shoal. The Hunter island was reported to have been situated in latitude 15° south, and in about longitude 166° east. It was described as of volcanic origin, well-peopled and cultivated, corresponding in most particulars to the island of Nui-fu, situated in about the same latitude, but in 176° west longitude. Many searching parties have been sent to look for it, but without success; two or three years since, the British Admiralty issued a notice that probably the two islands mentioned were identical, Hunter island having, through a typographical error, been transferred from west to east longitude.

I think it probable, however, that the island has sunk beneath the sea. The searching parties have found two or three shoals near its reported position, and one part of the original description of the island is so unique as to throw a doubt on the validity of the conclusion of the British Hydrographic Office. The little fingers of the left hands of all the inhabitants had been cut off at the second joint, and their cheeks were perforated. The first is a remarkable peculiarity that would undoubtedly attract the immediate attention of explorers, but nowhere else can I find mention of this maiming of the hand.

As to the best method of searching for dangers, I can offer no new ideas. There is no improvement upon the old plan of running on ranges, having one or more buoys ready to drop at a moment's notice. In deep-sea searching, the wire-sounding apparatus of Sir William Thompson, and that of Commander Sigsbee, are acknowledged by all to be not only useful as auxiliaries, but also *absolutely necessary*, if valuable results are to be expected. When a shoal is found it should, if possible, be examined from a boat. Even if the boat cannot go over the shoal, it can go near enough to be sure that the discoloration is not due to the presence of animalculae, or to breaking water carried on by the tide or currents. If the breakers are small, the boat can pull close around them and ascertain at once if there is an extension of the danger, a service that the ship could not satisfactorily perform on account of her greater draught. If time can be spared it would be well to take, not a single set of observations, but a series of sets on both sides of the meridian, or a series of three or four twilight observations, for Summer's lines. In the report, the officer should state definitely the point on which the chronometer errors depended, both before and after the discovery.

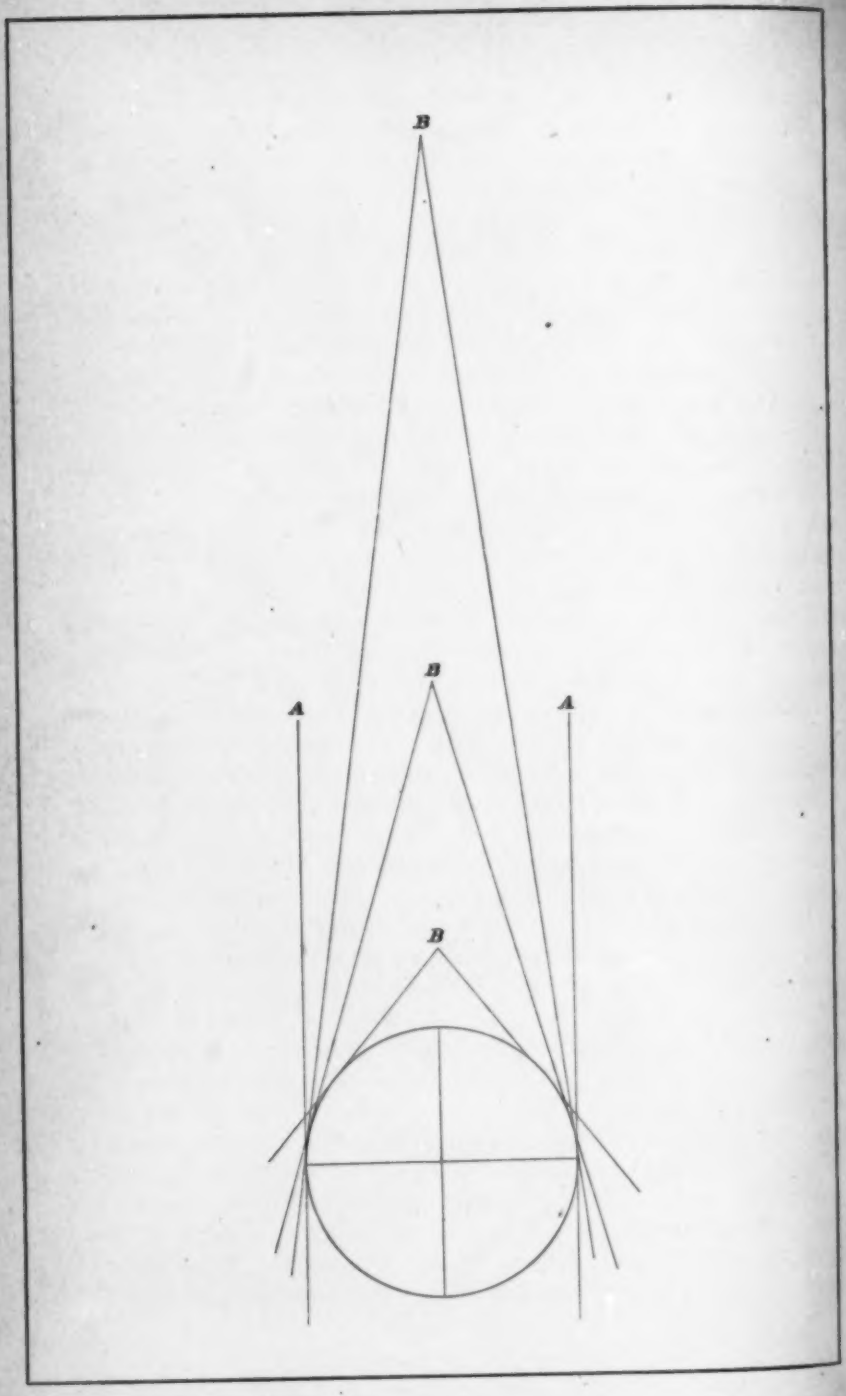
The Mercator projection for the construction of charts is the one in general, and I may say, almost universal use. It possesses an advantage which is deemed by most seafaring men an essential to a chart; any straight line drawn makes the same angle with all meridians. It has on the other hand no two consecutive miles of the same length, except on the parallels. The rhumb-line represents a part of a spiral, or practically a small circle of the earth. For a chart of the world, or for long distances, it is probably better to use Mercator's projection; but for small extents of surface, say 10 or 15, or at most, 20 degrees of longitude, the polyconic projection is far preferable, for the following reasons: 1st. It distorts to a less degree the configuration of the land or bottom; 2d. It has a scale

which may be taken from any point, on any meridian (preferably the middle one), and which may be used on any portion of the chart; and 3d. On the polyconic projection, a straight line is almost exactly part of a great circle of the earth; and by sailing on it we travel on the shortest possible line between the two points.

There are many objections named to the polyconic projection, and some of them I will mention. Recently, a commanding officer in the Gulf of Mexico noticed, I suppose for the first time, a chart on the polyconic projection. He was bound to New Orleans, and, calling his navigator, he asked how it was that the chartmakers could have made such a mistake as to curve the parallels. Another objected because he could not lay out a course on it with confidence, fearing every time that his landfall would be miles away from his port. Another said he could not plot a bearing to a distant peak, because the projection was curved and his bearing would be straight, forgetting that his line of vision was a straight line and followed in the plane of a great circle, and that on Mercator's projection all lines, except the meridians and equator, represent small circles of the earth. Another objected to this unwelcome innovation because he could not plot a position with a parallel ruler from the margin of the chart; and another, because he was accustomed to Mercator's projection. I suppose I have heard scores more of as reasonable objections, and probably you all have heard similar ones. If we are always to adhere to what is old, out of respect to the wisdom of our fathers, we shall never improve; but, perhaps, in future generations, when pounds, shillings, and pence, and ounces and pounds, are things of the past, eleven and a quarter degrees to a point of the compass will have gone too; and men who go to sea will not be afraid to use a chart simply because it is on the polyconic projection.

Without going into minute details, the simple conic projection is this: Imagine a cone surrounding the globe, its apex coincident with the earth's axes produced, and its surface tangent at any given middle parallel. Upon developing the cone, this parallel will be the arc of a circle having a radius equal to the slant side of the cone from the apex to the point of tangency. Parallels are struck from the same centre, and the meridians are straight lines. It will be seen that the lengths of the degrees of latitude are true. The degrees of longitude are in excess of the true below the middle parallel, and are less than the true above the parallel.

There are many modifications of this projection, the most valuable


B
B
A
A
B

of which are those of Bonne and those of Professor F. R. Hassler. In the former, the parallels are divided off from the middle meridian into parts the same as on the sphere, and through corresponding divisions the meridians are drawn. Lines on the sphere appear nearly the same on the projection, and the same scale may be used in all parts of the chart not exceeding a few degrees in extent. In the polyconic projection, instead of one tangent cone being used, there is one for every parallel, and, theoretically, an infinite number. Each parallel is therefore independently developed; but, on this chart also, the parallels are divided into the same proportional parts as on the sphere. A glance at the figure (1) will show the differences in the Mercator's, the Bonne's, and the polyconic projections. The Mercator's is projected to the cylinder *A*, tangent at the equator. Bonne's is projected to any one of the cones *B*, which are to be tangent at the middle latitude, and the polyconic is projected on the cones *B*, *B*, *B*, each tangent to successive parallels. At the equator the cone would have infinite altitude; hence, its sides become practically parallel. The effect of this projection to successive cones of different altitude is, upon development, to make the parallels of latitude curves; but the curves in a chart of the Gulf of Mexico, for instance, on a scale of $\frac{1}{12000000}$, will hardly be perceptible in short distances. The actual amount of separation between parallels 13° apart, measured at the edge of the chart, and in the centre at intervals of 10° of longitude, is eight miles, or only about two-thirds of a mile to a degree. This is so slight that the parallels may be called and used as truly parallel in a chart of this size.

The first advantage I named was that the polyconic projection distorts the least of all. This would seem to be true as shown from the figure, for the greater the angle of deflection of the plane on which the projection is thrown, the greater the distortion; as the setting sun will throw lengthened shadows, while a noonday sun throws true ones. On this projection the meridians are divided into an even number of proportional parts of the surface of the earth; that is to say, a scale of $\frac{1}{40000}$ means that one inch of paper equals 40,000 inches of the earth's surface; and as minutes of latitude are practically miles (and would be exactly equivalent if the globe were a perfect sphere), the subdivisions of any of the meridians are practically miles, and may be used as such taken from any part of the chart. To be exact, the distortion is least and the scale is truest on the middle meridian cut. The subdivisions of the parallels are minutes of longitude.

A chart on the polyconic projection of $\frac{1}{1200000}$ scale, or one foot of paper to 1,200,000 feet of the surface of the earth, including within its limits ten degrees of longitude, has its parallels at the central meridian, seven miles (in the latitude of Cape Henry) below the straight line joining the extremities of the parallel. This straight line disagrees with the great circle course on the surface of a sphere by less than *ten minutes* of azimuth taken at any point on it. On a Mercator's projection in the latitude of Cape Henry, on an east course, the difference is *two degrees and twenty-four minutes*, and on a northeast course nearly *two degrees* (Plate 2). For longer courses than this the straight line on the polyconic projection would still closely approximate to the true great circle; while on Mercator's projection, the longer the course the greater the error.

It would be very convenient to be able to lay off a course and feel sure that if you hold it you will arrive at the desired port, *other things not interfering*, even if you do take a little longer time and go a little further; *but other things do interfere*, and the course has to be changed daily, or perhaps oftener. In parts of the Atlantic, on our own coast, where the variation changes over half a point in a day's run, as between Cape Hatteras and Nantucket, a captain in a hurry, or one who believes in going by the shortest route, would probably change his course at every quarter point change of variation. Lay down a straight line on the polyconic projection, and that line is almost a true great circle. The initial course is the angle at which the course cuts the magnetic meridian at that point. After proceeding about seventy-five or one hundred miles the variation has changed, and you are a quarter of a point off the course in consequence, and also on account of the angle between the meridians, which is, in this distance, equal to about one degree. You change the course then, and continue changing as often as may be necessary to keep the line, and you will have practically sailed over a great circle. Upon a Mercator's chart also the courses can be regularly changed and the vessel made to traverse a great circle; but it is necessary that the circle shall be previously plotted, and for every deflection a new course must be computed or laid off; while on a polyconic chart, a great circle is obtained whenever a straight line is drawn.

As a matter of curiosity I show on Plate 2 a line that a vessel would follow by holding an east course and by neglecting to make allowance for changes in variation. The vessel will arrive upon a given meridian at a distance of about thirty miles north of the point which would have

76°
75°
74°
73°
72°
71°
CAPE MAY
CAPE HENLOPEN
CAPE CHARLES
CAPE HENRY
CAPE HATTERAS
A
Straight line on projection and great circle of sphere.
Rhumb or loxodromic line.

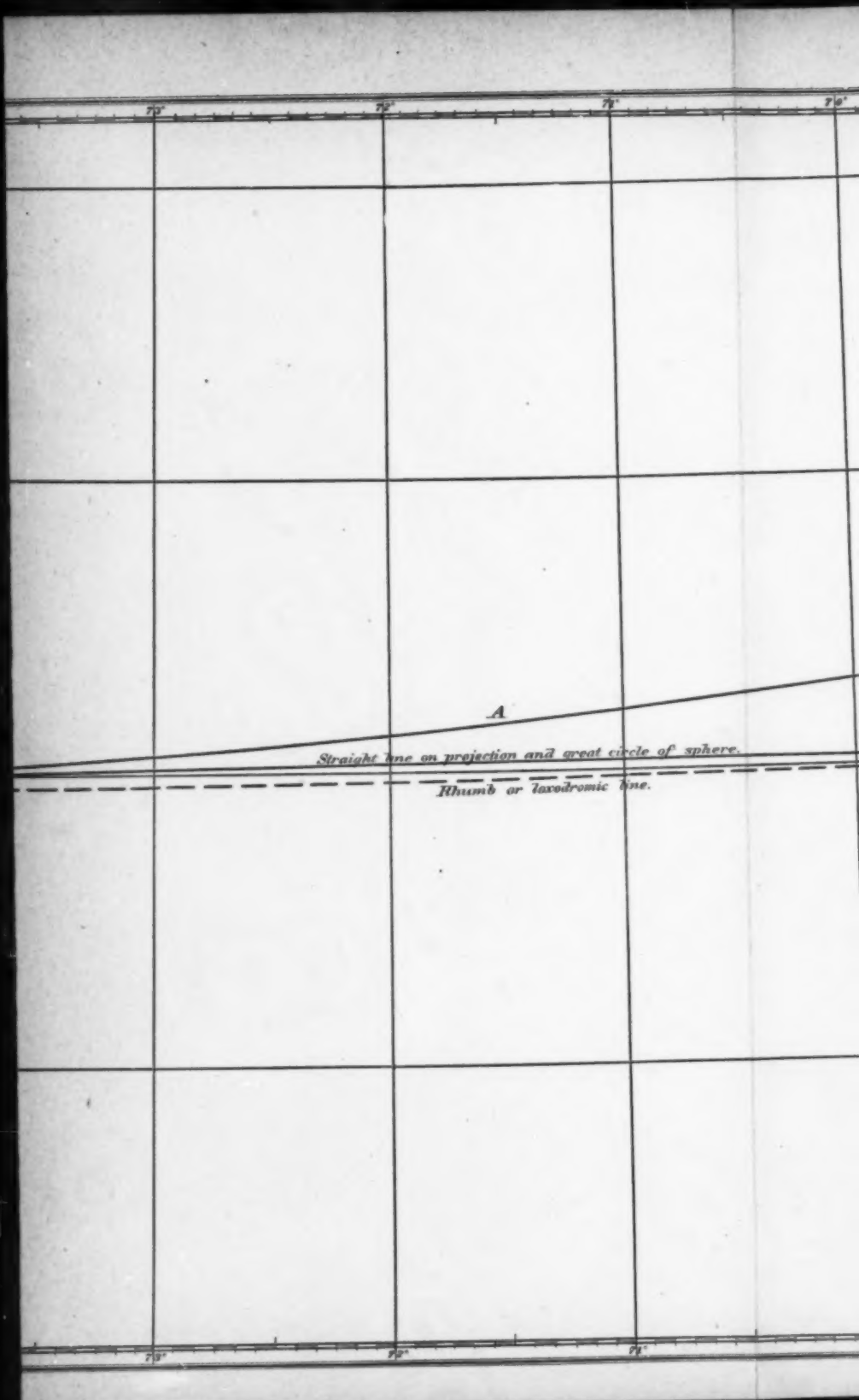

73°
72°
71°
70°
A
Straight line on projection and great circle of sphere.
Rhumb or loxodromic line.
73°
72°
71°

PLATE II.

been reached had allowance been made for the changes in variation. To make a fair day's run and reach a given point requires a careful study of the changes in the variation, if one course only is to be steered. Approximately, however, the mean of the variation will frequently answer for a single day's run. In the case before us, by the use of the mean variation we shall reach a point only four and a half miles south of our objective point in a run of three hundred and eighty miles. This discrepancy is owing to the irregularity in the change of variation.

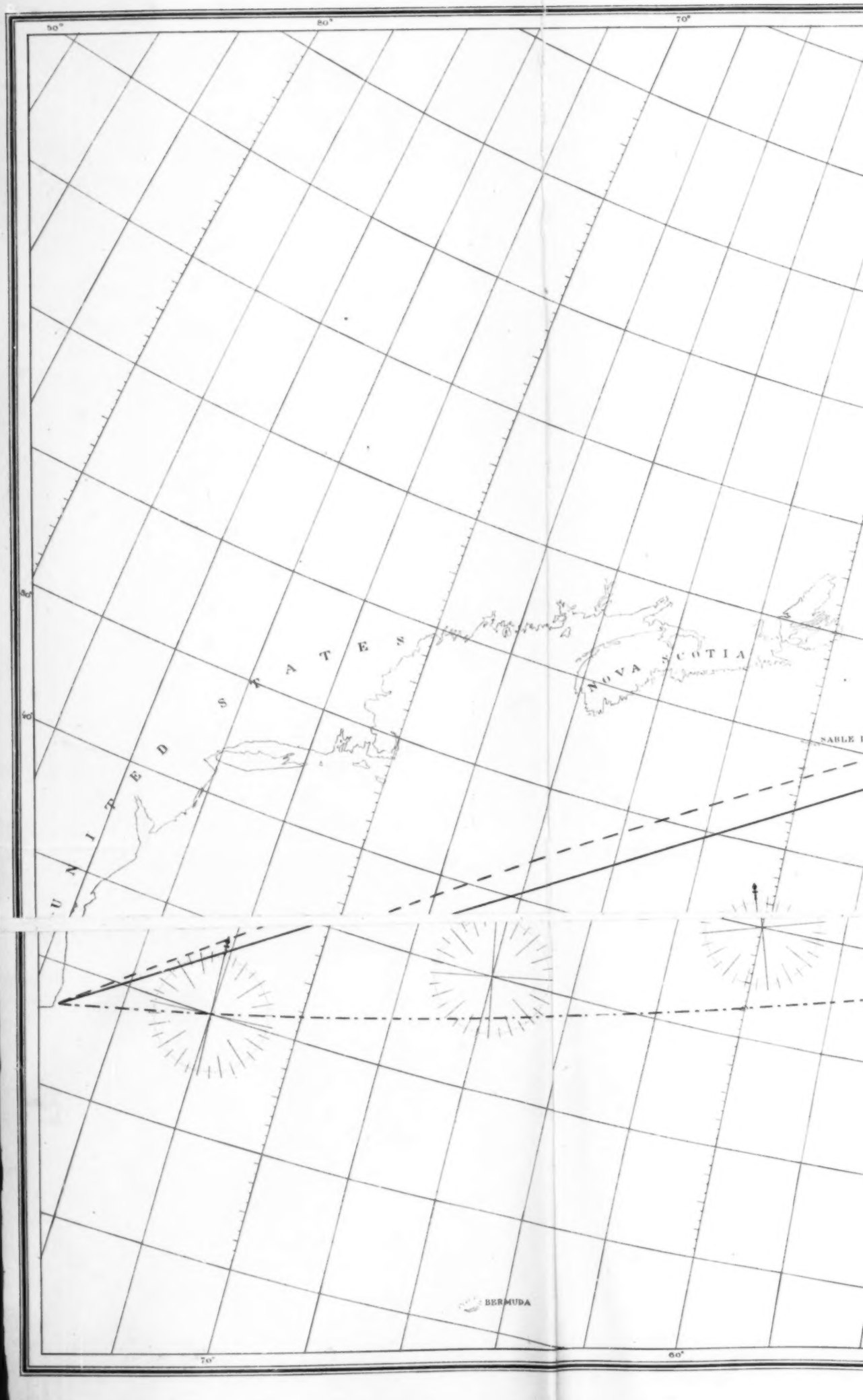
The operation of taking a course from a compass card is exactly the same on both of the charts in question, but with the advantage on the side of the polyconic, for as I have before stated, the new line is practically a great circle. In actual practice, running on an east course in this latitude, I would change every hundred miles if I wished to make a good passage; if not, I would lay one course, using the middle compass.

In plotting a position, it is but little work to lay off the latitude on the nearest meridian, and then, with dividers for the longitude, and a parallel ruler, the position may be plotted with greater accuracy than by laying it off at a long distance with the rulers, as on a Mercator's chart. It seems, then, that as far as accuracy and convenience in navigating are concerned, the polyconic chart is better, within small limits, than the Mercator's; as regards convenience, a strong point in favor of this projection is, that, in measuring we are able to take distance from the subdivisions on the meridians at any point on the chart, instead of carefully adjusting for the middle latitude (sometimes applying a correction), as on the Mercator's.

The question naturally arises, If this projection is considered best for charts of limited extent, why not for large ones?—and if not best for large charts, what is the greatest limit advisable? Plate 3 shows a chart on this projection of a portion of the Atlantic on a scale of $\frac{1}{30000000}$. The great-circle course, the straight line, and the rhumb-line are shown from Cape Hatteras to the English Channel. The great-circle course is only about forty miles distant from the polyconic straight line at its middle point, and nearly four hundred miles from the rhumb. It will be noticed at once that the parallels are curves, and that the meridians converge toward the top; but a close examination will reveal the fact that the meridians, except the central one, are also curves. An examination of this chart will show why it is that only limited areas should be represented on the polyconic projection. It

will be seen that the 10 degrees each side of the middle meridian do not vary much in scale, and for that distance the minutes of latitude measured on any meridian will not disagree with those of any other by more than 2½ minutes in 10 degrees; and any distance may be measured in any direction without an error greater than this. When we go farther from the middle meridian the disagreement of minutes of latitude is greater, as shown by the following measurements, beginning from 34° latitude: at 10° from the middle meridian the disagreement in 10° of latitude is 02′ 30″; 20° from the middle meridian the disagreement in 10° of latitude is 22′ 00″; and 30° from the middle meridian the disagreement in 10° of latitude is 50′ 00″. The great-circle course shown is 3064 miles. The polyconic straight line, measured by using the meridians, separated 30 degrees from the middle meridian, is 3007 miles long, and 3227 miles long by using the middle meridian. It is this distortion in scale between extended limits which makes it unadvisable to use the polyconic projection as a sailing chart.

There is another projection, however, which supplies the place of a great-circle sailing chart, and it is very satisfactory, as far as the great circle is concerned. I refer to the Gnomonic. This projection is one that uses a plane tangent at a central point, the eye being situated at the centre of the earth. All straight lines on it are great circles, but the scale of distances is as complicated as one formed for the polyconic chart would be, and is probably more difficult to use. As this difficulty is common to both charts, the Gnomonic is the best to use for a sailing chart, because it has this advantage, that the straight line is a great circle, while on the polyconic chart it only approximates to one. In my opinion, charts on this projection should be issued to naval vessels, not as an absolute necessity, for the course can be calculated, but as a labor-saving appliance which would be found very useful in making long voyages.


90°
80°
70°
UNITED STATES
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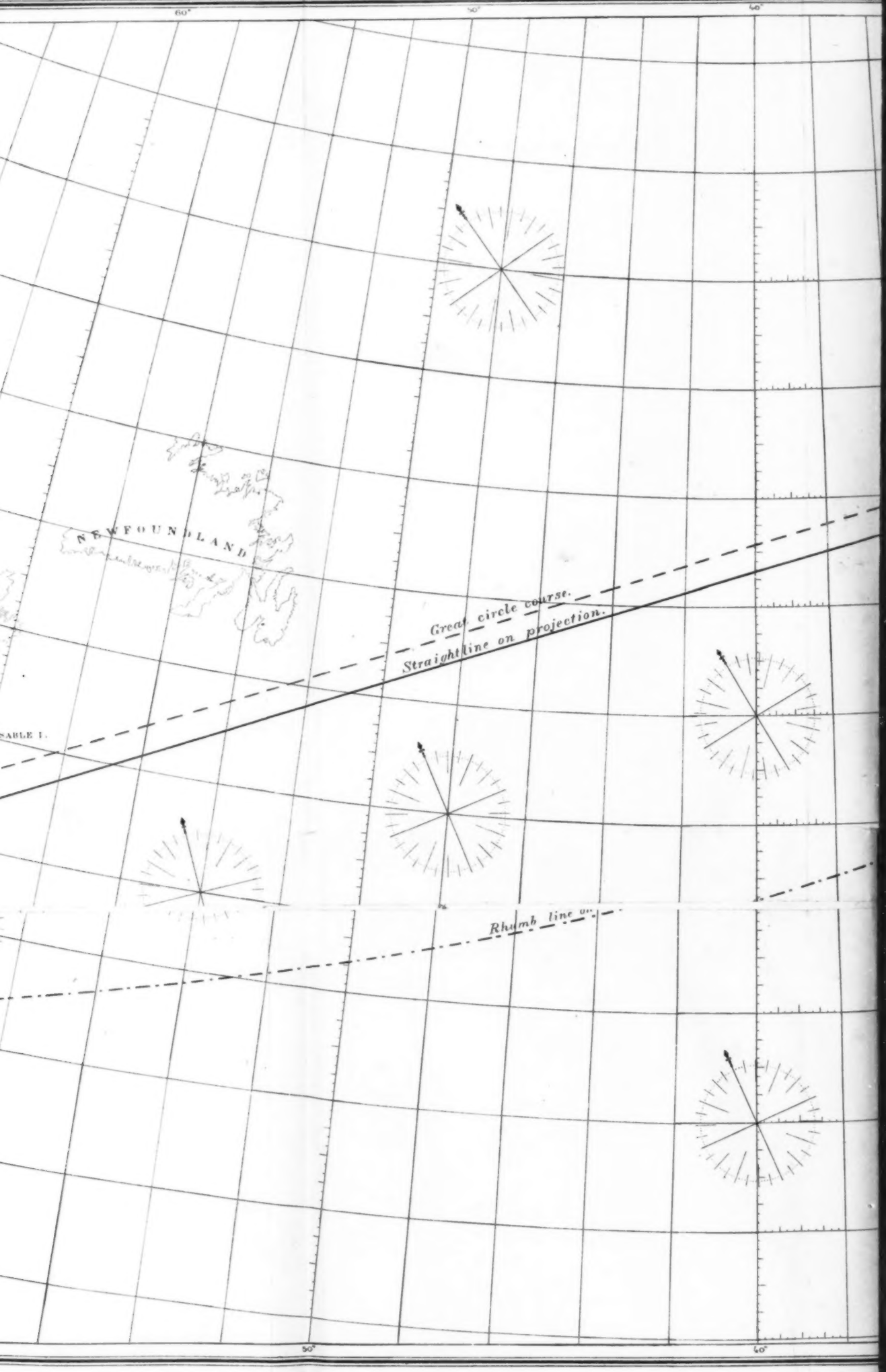
NORTH ATLANTIC OCEAN POLYCONIC PR